INTERNATIONAL ENERGY AGENCY

Combined Heat and Power

Evaluating the benefits of greater global investment

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At their 2007 Summit in Heiligendamm, G8 leaders called on countries to "adopt instruments and measures to significantly increase the share of combined heat and power (CHP) in the generation of electricity."

As a result, energy, economic, environmental and utility regulators are looking for tools and information to understand the potential of CHP and to identify appropriate policies for their national circumstances. This report forms the first part of the response.

It includes answers to policy makers' questions about the potential economic, energy and environmental benefits of an increased policy commitment to CHP. It also includes for the first time integrated IEA data on global CHP installations, and analyses the benefits of increased CHP investment in the G8+5 countries. A companion report will be produced later in 2008 to document best practice policy approaches that have been used to expand the use of CHP in a variety of countries.

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-seven of the OECD thirty member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies.

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
The European Commission takes part in the work of the OECD.

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Foreword

This report was prepared by the IEA Secretariat in March 2008 as part of the IEA G8 Programme of Work on Climate Change and Clean Energy. In July 2007, at the conclusion of the Group of Eight (G8) Summit in Heiligendamm, Germany, the leaders developed a communiqué to summarise key messages. Among other things, the communiqué directed countries to "...adopt instruments and measures to significantly increase the share of combined heat and power (CHP) in the generation of electricity." As a result, energy, economic, environmental and utility regulators are looking for tools and information to understand the potential of CHP and to identify appropriate policies for their national circumstances.

This report answers policy makers' first question: what are the potential economic, energy and environmental benefits of an increased policy commitment to CHP? It includes for the first time integrated global data on CHP installations, and analyses the benefits of increased CHP investment in G8+5 countries (the G8 nations, along with Brazil, China, India, Mexico and South Africa).

A second report, to be published later in 2008, will document "best practice" policy approaches in the energy, environmental, utility regulatory, financial and local planning arenas that have been used to expand the use of CHP. This second report will also include policy roadmaps for regulators and others seeking to implement the G8 Heilingendamm charge by adapting these policies to their particular situation.

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Executive Summary

Combined heat and power (CHP) represents a series of proven, reliable and cost-effective technologies that are already making an important contribution to meeting global heat and electricity demand. Due to enhanced energy supply efficiency and utilisation of waste heat and low-carbon renewable energy resources, CHP, particularly together with district heating and cooling (DHC), is an important part of national and regional GHG emissions reductions strategies.

However, while some countries have been able to achieve a high share of these technologies, most countries have been much less successful. Policy makers and industry are investing in policies and measures that increase the use of CHP and DHC as part of a larger portfolio of energy technology solutions. This report attempts to guide them by quantifying the associated energy, economic and environmental benefits that might result from greater use of these technologies. This report will be followed by a second report later in 2008 which will identify global best practice policies for CHP and DHC.

The report confirms that CHP merits a closer look by policy makers as they investigate paths toward a lower-carbon, more efficient, lower-cost and reliable energy future. Some key results of the analysis include:

- CHP can reduce CO_2 emissions arising from new generation in 2015 by more than 4% (170 Mt / year), while in 2030 this saving increases 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. CHP can therefore make a meaningful contribution towards the achievement of emissions stabilisation necessary to avoid major climate disruption. Importantly, the near-term reductions from CHP can be realised starting today offering important opportunities for low- and zero-cost GHG emissions reductions.
- Through reduced need for transmission and distribution network investment, and displacement of higher-cost generation plants, increased use of CHP can reduce power sector investments by USD795 billion over the next 20 years, around 7% of total projected power sector investment over the period 2005 - 2030.
- If the energy saving and capital cost benefits of CHP are allocated to its electricity production, growth in CHP market share can slightly reduce the delivered costs of electricity to end consumers. This is contrary to the common view that CHP and other decentralised energy solutions result in higher electricity costs to consumers.
- The specific potential identified for each country varies widely depending on different national circumstances and opportunities. For example, Brazil, a largely hydropower-based economy, is not expected to see such high growth as Germany, which is likely to be more dependent on fossil fuels and biomass. More work is needed in the Plus Five countries (Brazil, China, India, Mexico, South Africa) in particular to analyse the potential for CHP expansion.

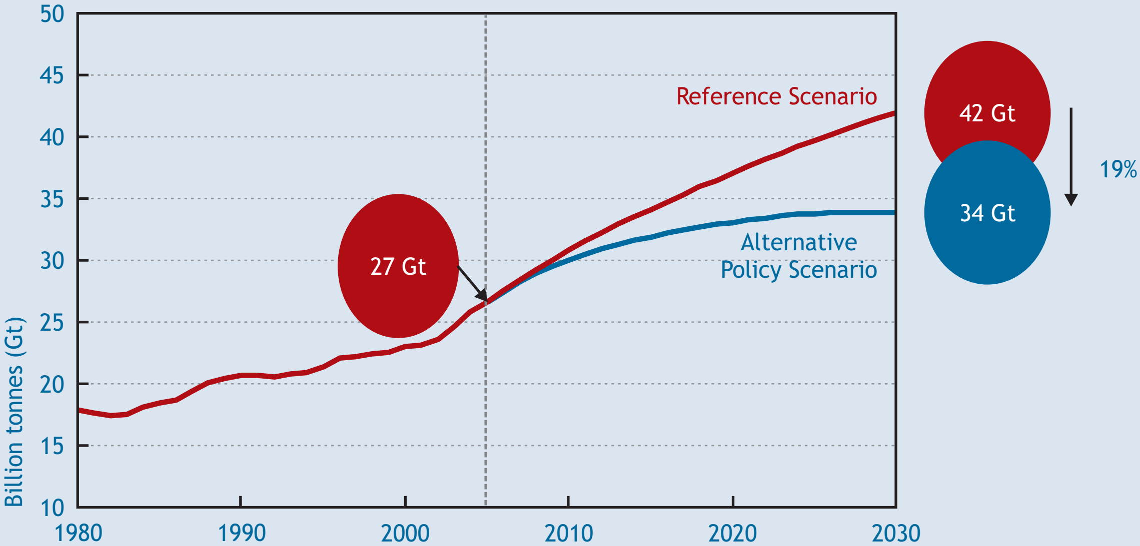
Based on these results, this report recommends the following next steps:

- Document and share specific best-practice CHP policy examples with a global audience, taking into account the different requirements of CHP with DHC, industrial CHP and buildings-based CHP;
- Convene groups of energy, environmental, economic and utility regulatory policy makers to better understand their needs as they attempt to invest in these technology solutions;
- Communicate the benefits of CHP/DHC expansion, and best practice approaches, to a variety of government and industry audiences; and
- Further analyse potential for growth in the Plus Five countries, to guide future development in these fast-growing areas with significant CHP/DHC potential.

Section 1 • Background

Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The threat of disruptive climate change, the erosion of energy security and the growing energy needs of the developing world all pose major challenges for energy and environmental decision makers. Despite important steps taken by government and industry to mitigate air pollutant and greenhouse gas (GHG) emissions, global energy-related carbon dioxide (CO_2) emissions have increased by almost a quarter in the past decade. Without further action, the world will continue to rely primarily on coal for power generation (IEA, 2007a). As a result, CO_2 emissions in the *World Energy Outlook* Reference Scenario are projected to rise 55%--from 27 gigatons (Gt) in 2005 to 42 Gt in 2030 (see Figure 1).

Figure 1 • World Energy Outlook: Global energy-related CO_2 emissions



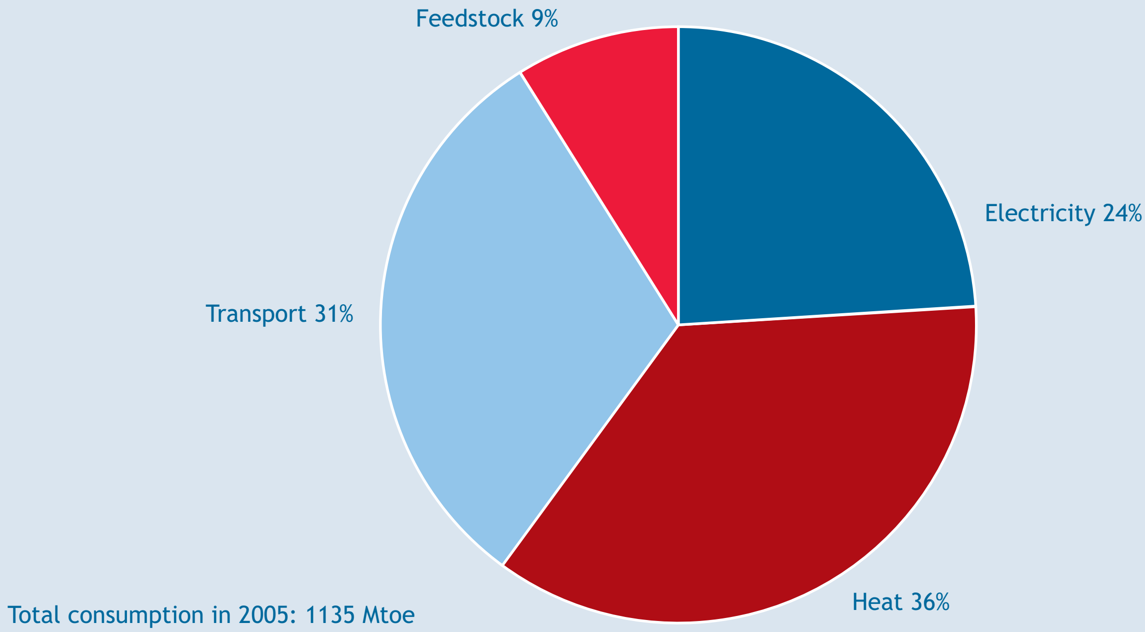
Source: IEA, 2007a.

This path urgently needs to be changed, using a portfolio of existing and emerging technologies – particularly in relation to the production and consumption both of heat and electricity. As an example of the importance of these two sectors, Figure 2 shows the share of overall energy demand that is taken by heat and electricity in the European Union (EU) 25 member states.

Nearly half of the necessary near-term GHG emissions reductions can be achieved through consumer efficiency measures; the remainder comes from a variety of energy supply options, including renewable energy, nuclear energy, clean fossil fuel with carbon dioxide capture and storage, and improved energy supply efficiency (IEA, 2006).

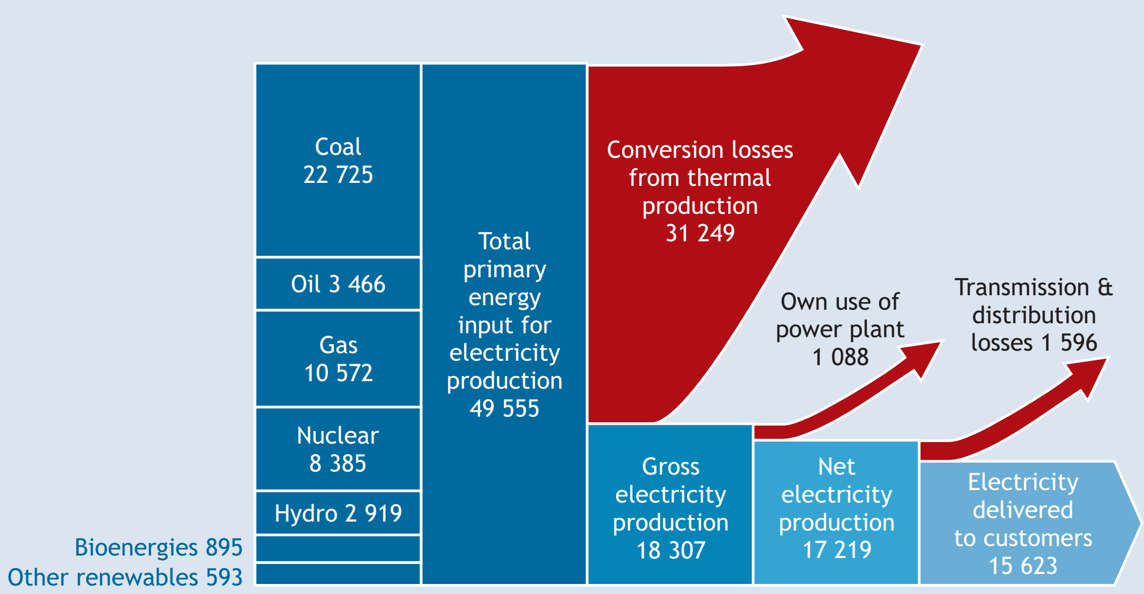
In particular, improving supply efficiency in the heat and electricity sectors offers an important near-term opportunity. For example, the average global efficiency of traditional fossil-fuelled power generation has remained stagnant for decades at 35-37% (IEA, 2006). About two-thirds of the primary energy that is converted to produce electricity is lost as “waste” heat (IPCC, 2007) that can, in part, be used to satisfy the demand for heat in industries, buildings, towns and cities. Further, the transmission and distribution (T&D) of this electricity from large central power stations contributes further losses of around 9% of net generation, so that only about one-third is delivered to the end customer. Figure 3 shows these losses for the global power system, demonstrating that 68% of total energy input is lost in energy each year before it reaches the end consumer.

Figure 2 • European Union energy demand in 2005



Source: Eurostat, 2007.

Figure 3 • Energy flows in the global electricity system (TWh)



Sources: IEA, 2007a; IEA, 2007d.

There are a variety of strategies for reducing this waste through increasing global average power plant efficiencies. For example, in coal-fired power plants, the use of pulverised coal combustion with supercritical (very high pressure and temperature) steam turbines offer an important opportunity to increase energy supply efficiency (IEA, 2007b). However, there are even more dramatic efficiency gains that can be realised by pursuing energy efficiency in the heat and electricity sectors simultaneously through greater use of combined heat and power and district heating and cooling. CHP and DHC include a family of proven, cost-effective technologies in the industrial, commercial and residential sectors that merit a closer look.

Why are policy makers and industry pursuing CHP?

CHP systems are attractive because they can deliver a variety of energy, environmental and economic benefits. These benefits stem from the fact that these applications produce energy where it is needed, avoid wasted heat, and reduce T&D network and other energy losses. Other benefits cited by policy makers and industry include:

- Cost savings for the energy consumer;
- Lower CO_2 emissions;
- Reduced reliance on imported fossil fuels;
- Reduced investment in energy system infrastructure;
- Enhanced electricity network stability through reduction in congestion and 'peak-shaving'; and
- Beneficial use of local and surplus energy resources (particularly through the use of waste, biomass, and geothermal resources in district heating/cooling systems).

Taken from: USEPA, 2008; Netherlands Environment Assessment Agency, 2008; US DOE, 2008; European Commission, 2008.

CHP economics

The primary rationale for most CHP investments is economic – that the project satisfies the profit requirements of the investor. In this sense, the economic benefit of existing CHP is clear. However, there is a growing range of evidence that the wider development of CHP in the future, beyond the traditional industrial and district heating markets, is a cost-effective means of reducing CO_2 emissions in the next several years:

- A study by McKinsey highlighted the part that can be played by CHP in achieving emission reductions in the USA. CHP alone provides around 13% of all identified negative cost CO_2 emission reductions (70 megatons) for buildings by 2030 and 53% of all negative cost reductions (80 megatons) for industry by 2030 (McKinsey, 2007).
- In a study undertaken to assess the cost of carbon abatement policies in the Netherlands, CHP was identified as one of the least-cost solutions at EUR25 / tonne CO_2, lower than building insulation, condensing boilers and wind power (RIVM / ECN, 2004).

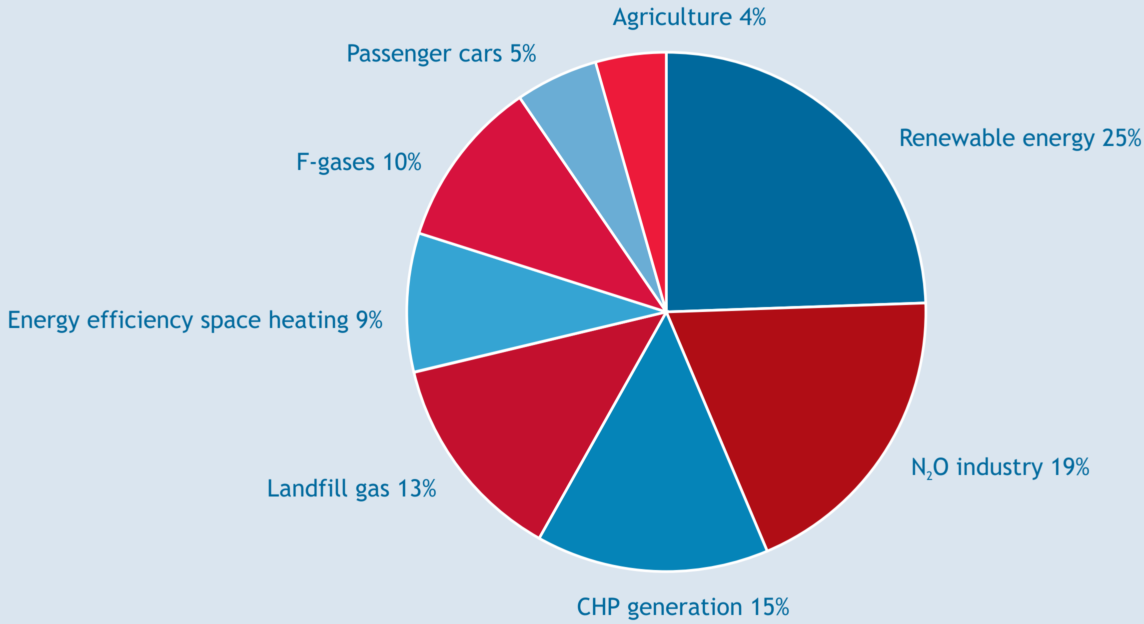
For example, in the USA, CHP achieves a 400 Mt annual reduction in CO_2 emissions (Hedman, 2007), and in Europe, CHP has been estimated to have delivered 15% of greenhouse gas emissions reductions (57 megatons) between 1990 and 2005, making it one of the primary solutions that EU countries relied upon to meet climate change targets (see Figure 4).

However, despite increased policy attention in Europe, the United States, Japan and other countries, the share of CHP in global power generation has remained stagnant for the past several years at around 9% (IEA, 2007c).

Figure 5 demonstrates that there are five countries that have successfully expanded the use of CHP to about 30-50% of total power generation: Denmark, Finland, Russia, Latvia and the Netherlands. Each of these countries has its own unique approach, but their collective experience demonstrates what can be achieved.[1] Figure 6 highlights the growth of CHP in Denmark over the past two decades, showing the parallel decline in GHG emissions that the country experienced, due in part to increased use of CHP and DHC.

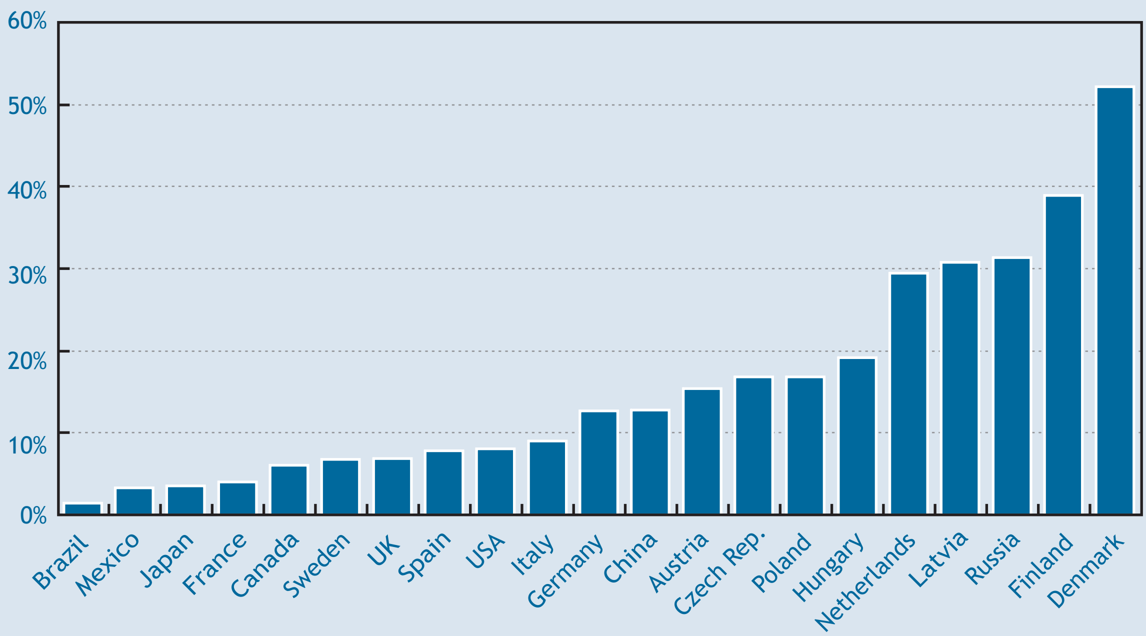
1. The IEA's International CHP/DHC Collaborative (see box Section 4) will publish case studies of some of these countries later in 2008.

Figure 4 • European GHG emissions reductions shares between 1990-2005 from different policy strategies;[2] reductions totalled 382 megatons.



Source: Netherlands Environment Assessment Agency, 2008.

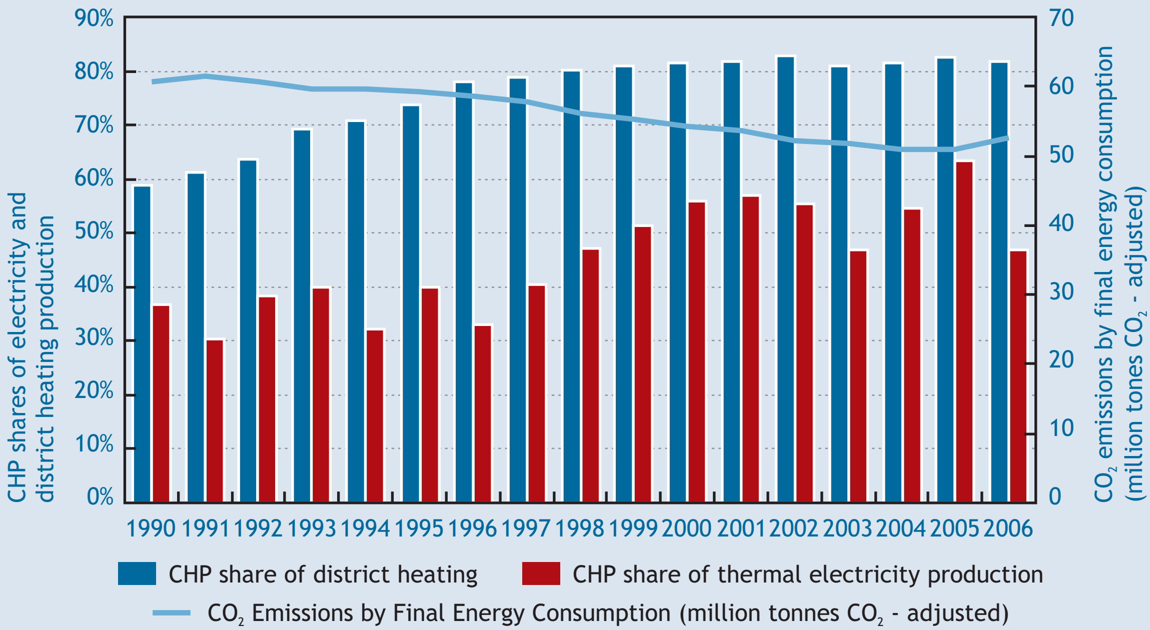
Figure 5 • CHP share of total national power production



Source: IEA data and analysis; data merged from years 2001, 2005, 2006.

2. This analysis looked only at policy-driven GHG reductions in Europe over this time period, and did not take into account other market-based GHG reductions.

Figure 6 • CHP/DHC growth and energy end-use carbon emissions in Denmark, 1990 - 2006



Source: Danish Energy Authority (2007).

The Netherlands has had a similar experience linking GHG emissions abatement with CHP growth, particularly through industrial CHP (Jeeninga et al., 2002). However, despite a number of policy and industry initiatives, it is clear that most countries are far from this level of CHP use. As one of many activities under the IEA G8 Programme of Work on Clean Energy and Climate Change (see forward), this report aims to begin to answer this question, using these countries' experiences as a guide.

The Purpose of this Report

This report delivers on the G8 request by providing policy makers, industry and other stakeholders with new analysis quantifying the potential stream of benefits that CHP can provide in an advanced policy scenario. This report is outlined as follows:

- **Section 2** describes the general benefits of CHP and DHC, along with a summary of technologies and applications, laying the groundwork for the analysis.
- **Section 3** includes improved data on current global CHP capacity, along with an accelerated policy scenario estimating the potential greenhouse gas reduction, energy efficiency, and cost savings benefits that CHP can deliver.
- **Section 4** includes recommendations for priority next steps, including a discussion of planned activities of the International CHP/DHC Collaborative.

What is CHP?

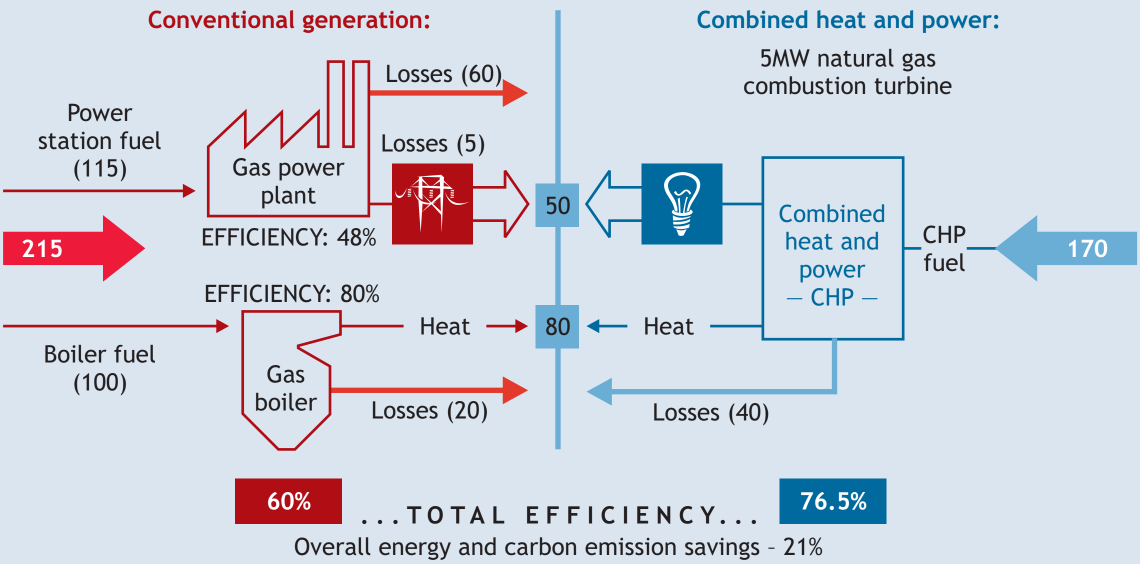
CHP is the simultaneous utilisation of heat and power from a single fuel or energy source, at or close to the point of use. An optimal CHP system will be designed to meet the heat demand of the energy user – whether at building, industry or city-wide levels – since it costs less to transport surplus electricity than surplus heat from a CHP plant. For this reason, CHP can be viewed primarily as a source of heat, with electricity as a by-product.

CHP can take on many forms and encompass a range of technologies, but will always be based upon an efficient, integrated system that combines electricity production *and* a heat recovery system. By using the heat output from the electricity production for heating or industrial applications, CHP plants generally convert 75-80% of the fuel source into useful energy, while the most modern CHP plants reach efficiencies of 90% or more (IPCC, 2007). CHP plants also reduce netwrok losses because they are sited near the end user.

CHP plants consist of four basic elements: a prime mover (engine or drive system), an electricity generator, a heat recovery system, and a control system. The prime mover, while driving the electricity generator, creates usable heat that can be recovered. CHP units are generally classified by the type of application, prime mover and fuel used.

Theoretically, almost any fuel is suitable for CHP, although for new systems, natural gas currently predominates. Other common fuel sources include fossil-fuel based commercial fuels (i.e. coal, diesel), municipal solid waste, and biomass. As biomass and industry-derived gases become more available and cheaper, they will be of increasing importance, due to growing environmental and energy security concerns. Some CHP technologies can use multiple fuel types, providing valuable flexibility at a time of growing fuel insecurity and price volatility.

Figure 7 • Efficiency gains of CHP: one example (all values HHV)



Source: IEA analysis, USEPA, 2008.

In electrical output terms, CHP plant sizes range from 1 kWe (kilowatt electric) to over 500 MWe (megawatt electric). For larger plants (greater than 1 MWe), equipment is generally site-specific, while smaller-scale applications can use pre-packaged units. The proportions of heat and power needed (also known as the heat:power ratio) vary from site to site. As a result, the CHP system must be selected to match these demands as closely as possible. Since CHP plants are usually sized to meet heat demand, any excess electricity can be sold back to the grid or supplied directly to another customer via a distribution system. Any additional electricity needs at the site are supplied by the grid; supplemental heat is typically supplied by stand-by boilers or boost heaters.

The efficiency gains from CHP vary depending upon the technologies and fuel / energy source(s) employed, and the heat and power generation systems displaced. Figure 7 compares the overall efficiencies of CHP and conventional "separate heat and power" generation.

Prime Movers

CHP prime movers are mature, reliable and proven technologies. The main types are steam turbines, gas turbines, reciprocating engines, and combined cycle systems. In all cases, fuel combustion creates mechanical energy directly, or first produces steam, which is subsequently converted to mechanical energy. The mechanical energy is used to spin a generator producing electricity. New developments are bringing emerging technologies to the market - including microturbines, Stirling engines, and fuel cells - as they improve their cost-competitiveness. CHP research and development is focused primarily on improved performance, higher reliability, modular and smaller units, and lower GHG emissions (e.g. through the use of biomass) (IEA, 2007c).

Generators and waste heat recovery

For traditional technologies, generators convert the mechanical energy in the rotating engine shaft into electricity. The heat recovery boiler is an essential component of a traditional CHP installation, as it recovers the heat exhausted by prime mover and generator. Heat exchangers provide for the simplest form of heat recovery, by transferring heat from the exhaust gases to the boiler to raise steam. The heat recovery systems are generally designed for particular exhaust conditions.

CHP applications

CHP systems can be utilised at most sites that meet the following criteria:

- A ratio of electricity to fuel costs of at least 2.5:1;
- Relatively high requirements for heating and / or cooling (e.g. annual demand for at least 5 000 hours);
- The ability to connect to the grid (if present) at a reasonable price with the availability of back-up and top-up power at reasonable and predictable prices; and
- Availability of space for the equipment and (for non-DHC related systems) short distances for heat transport.

The great majority of CHP applications can be grouped into three categories: industrial, commercial/ institutional, and DHC. CHP has a long history within the industrial sector, which has large concurrent heat and power demands, and in the district heating sector in countries with long heating seasons. However, advancements in technology development have led to the availability of smaller CHP systems, with reduced costs, reduced emissions and greater customisation. As a result, CHP systems are increasingly used for smaller applications in the commercial and institutional sectors, and are being incorporated more often into DHC systems. These applications are summarised in Table 1.

Industrial CHP

Energy-intensive industrial sites in the food processing, pulp & paper, chemicals, metals and oil refining sectors have been traditional hosts for CHP facilities; in fact, these industries represent more than 80% of the total global electric CHP capacities (IEA, 2007c). These plants generally have high process-related thermal requirements not subject to daily and seasonal weather-related fluctuations, so energy is an important part of their business, and operation and maintenance personnel are available and competent to manage CHP systems. In some industries, low-cost fuel sources (i.e. waste streams) are available for use in CHP systems. While industrial systems over 1 MWe make up the bulk of global CHP capacity, many smaller-scale industrial sites have smaller systems, utilising technologies similar to those used in commercial buildings.

Table 1 • CHP applications

Feature	CHP - industrial	CHP - commercial / institutional	District heating and cooling
Typical customers	Chemical, pulp and paper, metallurgy, heavy processing (food, textile, timber, minerals), brewing, coke ovens, glass furnaces, oil refining	Light manufacturing, hotels, hospitals, large urban office buildings, agricultural operations	All buildings within reach of heat network, including office buildings, 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	1 – 500 MWe	1 kWe – 10 MWe	Any
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	Steam turbine, gas turbine, waste incineration, 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 players	Industry (power utilities)	End users and utilities	Include local community ESCOs, local and national utilities and industry
Ownership	Joint ventures/ third party	Joint ventures/ third party	From full private to full public and part public/ private, including utilities, industry and municipalities
Heat/electricity load patterns	User- and process-specific	User-specific	Daily and seasonal fluctuations mitigated by load management and heat storage

Source: IEA Research.

The introduction and sizing of CHP in this sector depend on heat and electricity demand, and arrangements with the electric grid (both sales of surplus and purchases of back-up power). The grid can provide back-up power for many CHP plants during maintenance or down times, although different types of industrial facilities have different levels of tolerance for the loss of thermal load. Importantly, the availability and price of natural gas, the fuel of choice for most new industrial CHP systems, will be a key factor in the level of CHP development for the industrial market. It is expected that in the future, CHP can expand into new industrial applications with further research and demonstration to lower the costs of high-temperature CHP, fuel cell CHP, and micro-turbine CHP (IEA, 2006).

Case study: Apar industrial cogeneration project, Ankleshwar, India

Apar Industries Limited is a USD380 Million multidivisional group which manufactures aluminum conductors, polymers and speciality oils. Headquartered in Mumbai, its plant at Valia-Ankleshwar, Gujarat, India manufactures synthetic rubber. At this plant, power and steam are important energy inputs and have a major impact on their manufacturing cost. Apar Industries installed their first CHP plant in 2000. Their main fuel for energy generation is natural gas supplied by Gujarat Gas Company. The following economic and environmental performance data indicate the attractiveness of industrial CHP facilities when conditions are favourable.

System details

Power generator	Gas turbine generator of 1.5 MW
Steam generator	Waste heat boiler on turbine exhaust 4 TPH capacity at 10 kg/cm² pressure
Fuels used	Natural gas of 8800 kcal/NM³ calorific value
Inlet air temperature to gas turbine	Conditioned to 15°C with inlet air cooling
Type of chiller	Absorption chiller
Chiller capacity	145 USRT at 7°C water temperature

Environmental performance

Cogeneration system efficiency	63.59%
Overall efficiency of separate grid power and boiler for steam	55.70%
GHG emissions avoided	4 017 t CO_2 / yr

For base case GHG calculations, it has been assumed that 55% of the electrical energy from the grid would have been carbon dependant. Steam generation has always been from Natural Gas and hence no GHG reduction has been taken in to account.

Economic performance

Total project costs	USD 1 760 000
CHP plant operating costs	USD 705 000/yr
Costs of separate generation of steam and grid electricity	USD 1 220 000/yr
Annual savings	USD 515 000/yr
Payback period	3.4 yr

Source: Thermax India Ltd.

Commercial, Institutional and Residential CHP

In recent years, the use of CHP in commercial buildings and multi-residential complexes has increased steadily. This is due largely to technical improvements and cost-reductions in smaller-scale, often pre-packaged, systems that match thermal and electrical requirements. Examples of commercial and institutional CHP users include hotels, offices, and hospitals, which tend to have significant energy costs as a percentage of total operating costs, as well as balanced and constant electric and thermal loads (the temporal coincidence of heating / cooling demand with electricity demand can be particularly important for these applications).

Many owners of commercial and residential properties are not aware of opportunities to install CHP, as energy is not part of their core business, limiting application of CHP technologies. However, commercial companies are increasingly considering CHP as a cost-effective way to reduce their carbon footprint. Residential "micro" CHP technologies are also beginning to be developed and sold at the individual household level, and thus represent a potential mass market CHP product, provided fully competitive and reliable products can be brought to market (Japan Gas Association 2007; COGEN Europe 2008).

Case study: Shanghai Pudong International Airport

System details

Power generator	Gas turbine generators of 4 600 kW
Steam generator	Heat recovery steam generator, producing 11 tonnes / hour at 8 bar, 185 °C
Fuels used	Natural gas
Type of chiller	Absorption Chiller

Shanghai Pudong International Airport operates a CHP plant which generates combined electricity, heating and cooling for the airport's terminals at peak demand times. It is fuelled by natural gas.

The system operates 16 hours per day to offset peak energy demand of the airport. This improves local reliability and reduces overall energy costs. The energy use of the airport is substantial, with electricity demand around 28 MW and heat demand between 20 and 65 tonnes / hour. The CHP system meets 20% to 30% of the airport's electricity demand and 15% to 50% of its heat demand, depending on the season.

Environmental performance

CHP electrical efficiency	29%
CHP total efficiency	74%
NO_x emissions	5 - 25 ppm

The overall efficiency of the Pudong Airport CHP system is significantly higher than that of network electricity and on-site heat generation. It therefore contributes to both cost and CO_2 emissions reductions. The NO_x pollution from the system is also estimated to be less than coal-fired electricity generation.

Economic performance

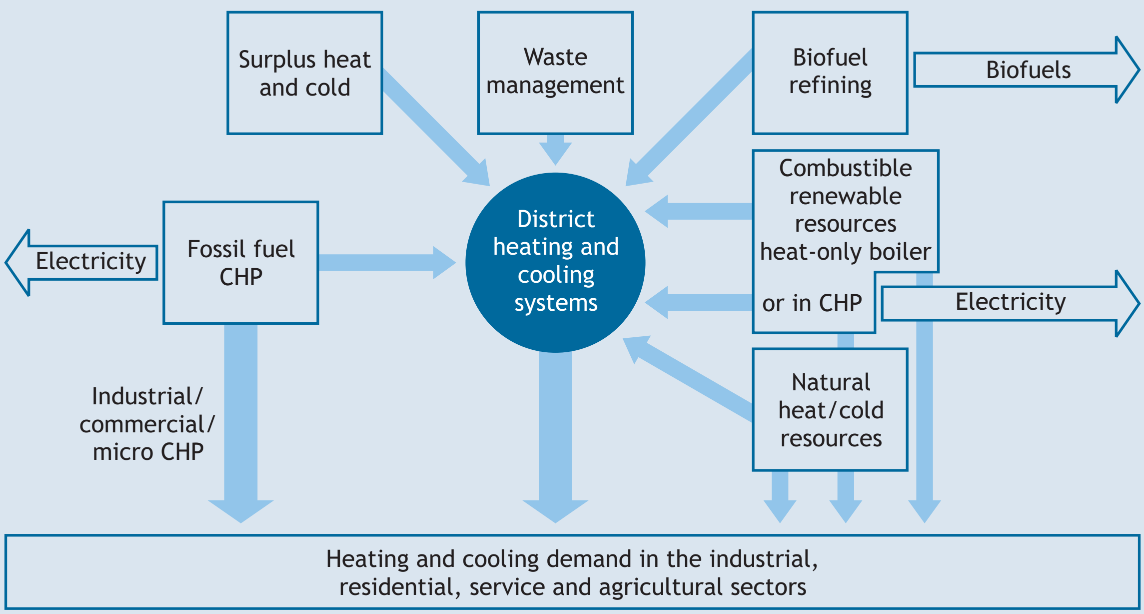
Installed costs	USD 5 400 per kW
O&M costs	< USD 3.00 per MWh
Fuel costs	USD 8.5 per MWh
Project lifetime	25 years
Payback period	< 6 years

Source: Solar Turbines.

District Heating and Cooling and CHP

District Heating primarily focuses on supplying low- and medium-temperature heat demands (i.e. space heating and hot tap water preparation), by "recycling" upgraded waste heat from CHP plants, industrial processes and waste incineration. DHC systems are also increasingly being used as a way to introduce renewable energy resources into heat and electricity sectors. The heat serves to warm up water which is transported via a well-insulated network of pipes to the customer premises. It can cover heat demands in residential, public, and commercial buildings as well as low-temperature industrial heat demands. A heat exchanger serves as interface between the district heating network and the building's own radiator and hot tap water system. District cooling takes advantage of natural cooling from deep water resources as well as the conversion of waste heat via absorption chillers.

Figure 8 • The diversity of resources used by district heating and cooling systems



Source: Euroheat and Power.

In most cases, the decision to install a CHP plant as part of a DHC system will hinge on the same factors as for an industrial installation, including: the timing and nature of the thermal load, fuel availability, and opportunities for the economic use of the electricity. However, population density is also a key consideration, because DHC systems rely on a concentrated demand for space heating/conditioning. This is important because of the need to minimise the distances that heat can be transported, and due to the high costs of installing heat distribution systems.

Countries with the largest number of heating degree days tend to have the greatest penetration of district heating. Moreover, due to the highly capital-intensive nature of these systems, DHC supports a greater level of local government involvement in providing services. As a result, DHC systems may be communally owned, but funded by public and/or municipal authorities. District cooling is being increasingly pursued as an alternative to conventional electricity- or gas-driven air conditioning systems. Due to the use of resources that would otherwise be wasted or difficult to use, district cooling systems reach efficiencies that are between 5 and 10 times higher than with traditional electricity-driven equipment (Euroheat and Power, 2008). They can contribute to avoid electricity peak loads during cooling season, offering cost savings and reliability benefits.

Case study: Finland: a community approach to CHP and DHC integration

Finland demonstrates how to utilize local solutions and careful CHP/DHC planning to optimize fuel use. The country has aggressively pursued DH and CHP integration, mostly through limited municipality companies. These companies maintain DH networks, produce heat and electricity and market it to their customers, as well as the Nordic market. As part of Finland's investment in the efficient use of fuels, CHP has been promoted and integrated into the DH network. As a result, district heating made up almost 50% of the space heating market in the year 2001, with 75% of the heat supplied by CHP plants. In addition, over 70% of fossil and biomass electricity generation comes from CHP (IEA, 2003).

The national government provides, on a limited basis, a subsidy for small-scale CHP generation, but this subsidy is less than the one for renewable technologies like wind. Innovative energy sector regulations allow DH companies to set their own heat tariffs, and customers are free to purchase competing systems, making it essential that DH be a cost-competitive source of heat. Doubtless, one of the key drivers of success in creating high-CHP penetration was the construction of a modern, efficient and accessible district heating network, as well as the ability to sell electricity to the grid.

Helsinki, the capital of Finland, has over 50 years of experience with DHC and CHP. The market share of DH is over 92 % of the heating demand in the city (or 7 TWh/a) and the CHP share of this exceeds 92 % annually. The amount of CHP-generated electricity is larger than the need in the capital, so Helsinki Energy sells electricity to the Nordic market. The origins of the system were built on a market-economy basis, without any subsidies. Recently, DC has also been developed and now forms part of the tri-gen system, which has been expanding rapidly. In 2005 Helsinki Energy had 32 MW of installed DC capacity, with projections to grow to 250 MW by 2020. The success of DHC and CHP in Finland shows that when planned well, DHC networks combined with CHP can be successful, even in a liberalised energy market. More information can be found at: http://www.helsinginenergia.fi/en/index.html.

Source: Helsinki Energy (2008) and IEA (2003).

This section has summarised CHP technologies and applications that are in the market today. The next section will present global CHP data and analysis of possible benefits that CHP can deliver in the future.

Section 3 • Global CHP Status, Potential for Benefits in an Accelerated Scenario

This section includes an overview of the current global status of CHP development, incorporating new data from 43 countries. To investigate the potential impacts of an accelerated CHP growth path for the G8+5 countries, this data was input into a model to quantify the potential benefits that could arise, including GHG emissions reductions, economic benefits and consumer energy savings.

CHP today – current status

The IEA has gathered data from around the world in order to assess the current share of CHP electricity generation of total national electricity generation.[3] Two challenges have confronted this task:

- Not all countries systematically collect CHP data.
- Where countries do collect data, they tend to use similar methodologies. However, there is no international definition or standard to ensure that all data reported as CHP are truly comparable. The main exception to this is the EU, where there is a standard methodology across all its member states.

Qualifying definitions for CHP

Policy makers have created definitions in order to calculate national CHP capacity/generation and to ensure that incentives are properly targeted at schemes that meet defined criteria, usually based on the system's overall energy efficiency. At present, there is a lack of international agreement on "good" or "high-quality" CHP. This is one reason why different countries continue to measure national CHP shares in different ways. Nonetheless, the two examples below indicate that solutions can be found, and may be useful models for other jurisdictions.

EU Cogeneration Directive (2004/8/EC), Article 11 (EU, 2004)

"High efficiency cogeneration is in this Directive defined by the energy savings obtained by combined production instead of separate production of heat and electricity. Energy savings of more than 10 % qualify for the term 'high-efficiency cogeneration'. To maximise the energy savings and to avoid energy savings being lost, the greatest attention must be paid to the functioning conditions of cogeneration units."

UK Government CHP Quality Assurance scheme (DEFRA, 2000)

"CHPQA provides a methodology for assessing the quality of CHP Schemes in terms of their energy efficiency and environmental performance. This methodology is based on Threshold Criteria, which must be met or exceeded in order for the whole of the Scheme to qualify as 'Good Quality'. Threshold Criteria are set for Quality Index and Power Efficiency, and both can be determined from just three sets of data: fuel used, power generated and heat supplied."

To address this lack of data and the definitional issues, the IEA has collected reliable and comparable CHP data from over 40 countries. Taking into account the differences in methodologies between countries and the depth of research that these countries undertake, the IEA believes that this new data on current CHP status, as well as being the most comprehensive available, is sufficient to form a solid basis for the potential and benefits modelling discussed below.

3. The analysis includes only electricity directly associated with heat production and use, and excludes other electricity not associated with heat use.

Table 2 summarises current estimates for global capacity therefore currently stands at 330GWe. CHP capacity for those countries where data was collected.[4]

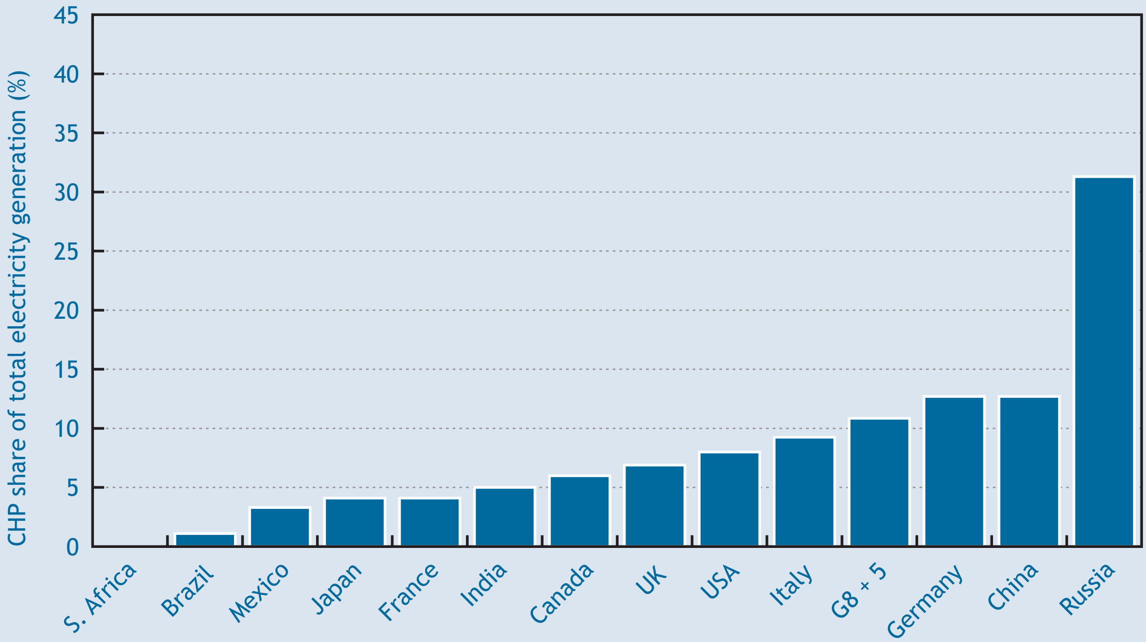
Table 2 • Installed CHP capacities (MWe)

Australia	1 864	Greece	240	Portugal	1 080
Austria	3 250	Hungary	2 050	Romania	5 250
Belgium	1 890	India	10 012	Russia	65 100
Brazil	1 316	Indonesia	1 203	Singapore	1 602
Bulgaria	1 190	Ireland	110	Slovakia	5 410
Canada	6 765	Italy	5 890	Spain	6 045
China	28 153	Japan	8 723	Sweden	3 490
Czech Republic	5 200	Korea	4 522	Taiwan	7 378
Denmark	5 690	Latvia	590	Turkey	790
Estonia	1 600	Lithuania	1 040	United Kingdom	5 440
Finland	5 830	Mexico	2 838	United States	84 707
France	6 600	Netherlands	7 160		
Germany	20 840	Poland	8 310		

Source: IEA data and analysis; data merged from years 2001, 2004, 2005, 2006.[5]

Figure 9 presents results from the same analysis for the G8 and Plus Five countries, presented in terms of the CHP shares of total national generation.

Figure 9 • G8+5 countries: CHP as a share of electricity generation



Source: IEA data and analysis; data merged from years 2001, 2005, 2006. [6]

4. Note: This data was collected from a variety of sources, including Eurostat for EU data, the U.S. Department of Energy for U.S. data, and the Japan Gas Association and Japanese Ministry of Energy Technology and Industry (METI) for Japan, among several other sources. Not all countries surveyed by IEA are included; some countries do not collect capacity data, others do collect this data, but not all their CHP capacity can be fully counted because many plants operate for part of the year as conventional power plants).
5. The source for the Spain figure is the National Energy Commission of Spain (www.cne.es). Eurostat, the source for all other EU member states in this table, gives a 2005 figure for Spain of 3,050 MWe.
6. Note: while IEA research found anecdotal references to a few industrial CHP facilities in South Africa, the national statistics agency does not confirm this data.

In general, with the exception of Russia, CHP makes a relatively small contribution to electricity production in the major countries. There is, however, some variety among countries, which can be explained by different national circumstances. For example:

- Germany has made more progress in increasing the contribution of CHP, in particular based on district heating and industrial CHP because of the incentives it provides.
- Brazil, where the relative demand for residential and commercial heating is much lower, has based its electricity system on the development of large-scale and remote hydro generation. Only in recent years has a market for CHP opened up, based mainly in the industrial sector with a particular focus on bagasse-based CHP in sugar cane mills.
- Russia, with a significantly higher share than the other countries, has a long tradition of heat supply to all sectors through DH networks linked to power plants. It has extended this energy supply model throughout the country.

CHP potential – An accelerated CHP scenario

CHP currently accounts for around 9% of global power generation (IEA 2007c). Its economic potential, however, is likely to be significantly greater. For example, the following countries have identified the potential for CHP, each using different assumptions:

- A number of European CHP potential studies cite CHP potentials, in the range from 150 - 250 GW (IEA 2007c) and more than a doubling of CHP capacity by 2025, giving a CHP electricity capacity share of more than 17% (COGEN Europe 2006). EU CHP potential analysis is ongoing and will improve in the future, as the European Union CHP Directive is implemented[7]. The CHP Directive requires member states to undertake comprehensive national studies of the potential for CHP.
- The Canadian government, in 2002, identified a potential for CHP, under a “CHP Promotion” scenario, of 15.5 GWe in 2015, around 12% of projected national capacity (current CHP share of generation is about 6%) (Strickland, C. and Nyboer, J, 2002).
- Estimates of CHP potential in the US range from an additional 48-88 GW of new CHP potential (IEA 2007c) to 110-150 GW (excluding CHP / DHC) (Hedman, 2007). If this second scenario was implemented by 2015, the CHP share of total electric capacity would rise from a current level of 8% to 12-21%.
- The UK CHP economic potential study undertaken by the UK government identified an economic potential for CHP of 17% of total national power generation by 2010 (currently 7.5%), with a potential for an additional 10.6 GWe of CHP on top of the current level of 5.4 GWe by 2015 (DEFRA, 2007).
- The German CHP target was in 2007 raised to 25% (a doubling of the current share) in 2020, based on a National Potential Study conducted by the government under the European Union's CHP Directive. This study also cites economic CHP potential to be up to 50% of electricity capacity (Germany Ministry for Environment, BMU, 2007).
- In India, the additional potential for industrial CHP alone has been identified as exceeding 7,500 MWe (Powerline, 2007).
- CHP potential in Japan for 2030 has been identified as up to 29.4 GW, around 11% of projected total capacity for that year (METI, 2005).

Given the existence of these existing and planned studies, for this analysis, a simple "top-down" approach was chosen, rather than a detailed "bottom-up" approach that might, for example, study specific CHP candidate sectors and assign growth rates to each, taking into account national circumstances. The “top-down” approach can be compared with existing CHP potential studies which have been

7. Annex IV of the European CHP Directive, Criteria for Analysis of National Potentials for High-efficiency Cogeneration, includes a number of criteria that Member States must consider. *See* Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC, Official Journal L 052 , 21/02/2004 P. 0050 - 0060.

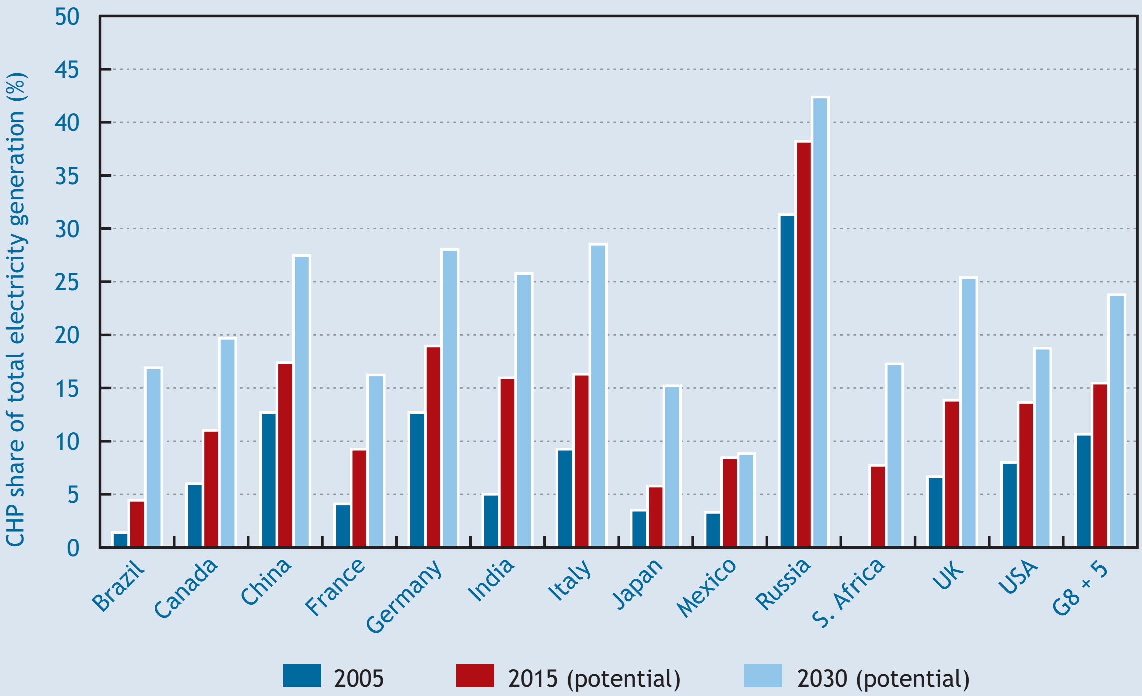
undertaken by some of the countries, using a wide range of different methodologies and approaches. Given the G8 ministers' charge to enact CHP-friendly policies, the more pressing need is to estimate the potential benefits of expanded CHP use, as a way to guide these future CHP policies.

The level of CHP development in a country depends on heating and cooling demand in the industrial, commercial and residential sectors. This demand was used as the basis for the approach taken to analyse CHP potentials: to estimate, taking into account different national circumstances, the proportions of current and future heating / cooling demand in each of the countries that could be reasonably served by CHP.

The assumption underpinning these estimates was that there exists a pro-CHP policy regime (for example removing barriers to CHP and introducing targeted incentives) that corresponds to rates of CHP development that approach the rates seen over the last three decades in countries like Denmark, the Netherlands and Finland. The validity of the estimates can be tested by comparing the output potentials with the CHP shares in these countries. Information about the assumptions and methodology behind this Accelerated CHP Scenario (ACS) is provided in Annex 1; the outputs are shown below.

Figure 10 shows the expected rise in CHP as a share of national electricity generation. Countries are expected to see a small increase until 2015, with a correspondingly larger growth by 2030 as policies are enacted and begin to be widely implemented. As a whole, in the G8+5 the share of CHP rises from 11% of electricity generation today to 15% in 2015 and 24% in 2030.[8]

Figure 10 • G8+5 countries: CHP potentials under an accelerated CHP scenario, 2015 and 2030



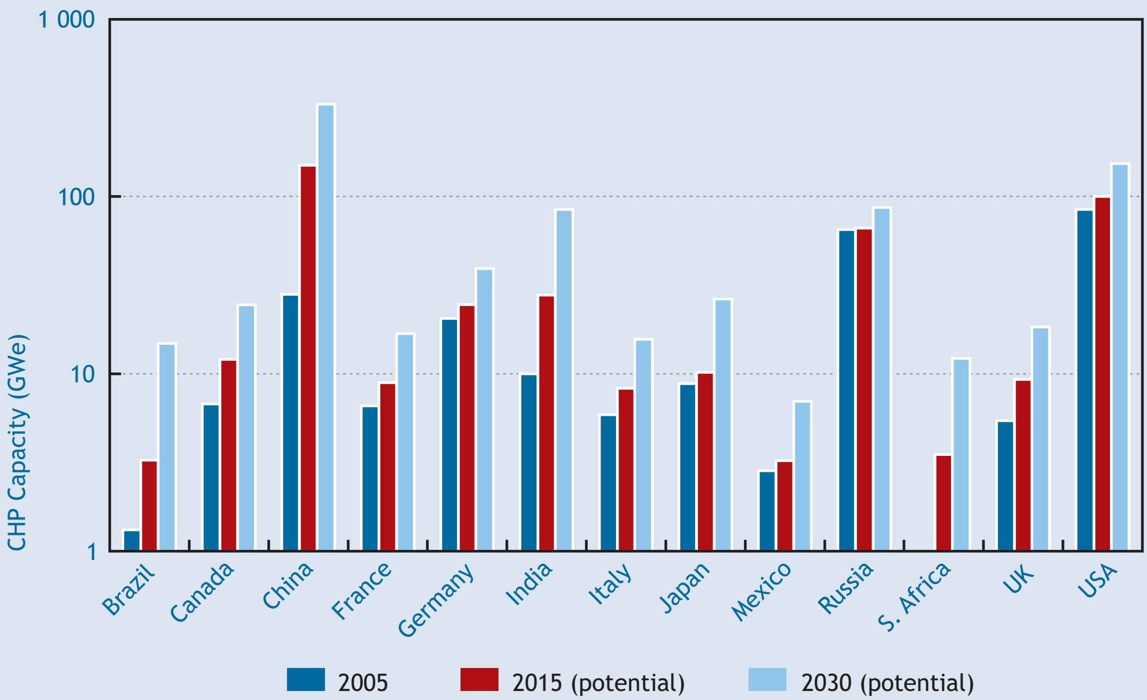
Source: IEA data and analysis.

8. Note: this analysis does not attempt to include longer-term (e.g., to 2050) impacts on CHP use from expected tightening of GHG constraints as the world attempts to move to a zero-carbon energy sector. For analysis on this, see *Energy Technology Perspectives 2006* (IEA, 2006), and its planned successor, *Energy Technology Perspectives 2008* (to be published in June 2008).

CHP application and fuel use will vary greatly depending on the country concerned. For example in China, a considerable proportion of CHP in the short-term is likely to be based on coal and used in district heating and industrial applications. In the period to 2030, greater use of natural gas and renewable fuels is envisaged, with the development of smaller applications providing both heating and cooling at the individual building level. In France, by contrast, gas is likely to be the predominant fuel for CHP in the short term with the share of renewable fuels growing as the market moves beyond 2015.

Figure 11 presents the potentials highlighted in Figure 10 in CHP capacity terms, based on expected load factors that again take into account different national circumstances. Under the ACS, the G8+5 countries reach almost 430 GWe of CHP capacity in 2015, and over 830 GWe in 2030.

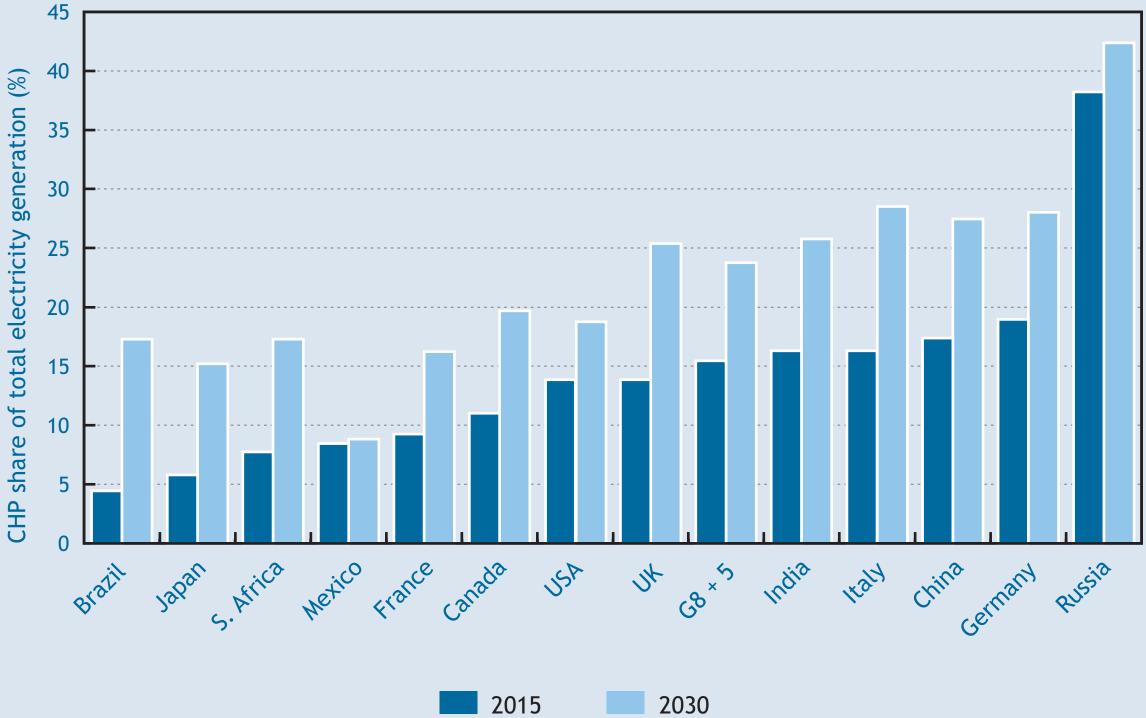
Figure 11 • Current and projected CHP capacities under an accelerated CHP scenario, 2015 and 2030



Source: IEA data and analysis.

Figure 12 below presents the same data as figure 10, but provides a ranking of countries for the two years 2015 and 2030. Again, different national circumstances explain the different results. Brazil, for example, is projected to remain a hydropower-based economy (IEA 2007a). It will consequently have less opportunity for CHP. Similarly, a high growth in end-use energy efficiency is projected for Japan (IEA 2007a). This is an important reason why there is less scope for CHP investment there than in other countries where heating/cooling and electricity demand grow faster. The relatively slow growth of industrial energy demand in Mexico also explains why CHP grows more slowly there. Russia, by contrast, is already a heavy user of CHP and given projected high energy demand growth there, CHP has a clear opportunity to expand even more widely.

Figure 12 • G8+5: CHP share of electricity generation in 2015 and 2030 under the accelerated CHP scenario



Source: IEA data and analysis.

The benefits of increased use of CHP

To analyse the benefits of achieving the CHP potential that could be realised in the 13 countries, the IEA adapted an existing model developed by WADE (the World Alliance for Decentralized Energy).[9]

In summary, the model 'builds' new power generation, according to user-defined preferences, to meet future electricity demand growth and to replace some capacity that already exists today but will be retired in the future. The model thus allows the user to determine different power generation mix scenarios to meet future energy demand. The model then produces outputs that compare the different scenarios in economic and environmental terms.

For this analysis, the model was programmed to build, and compare, two scenarios: the Accelerated CHP Scenario described above and the IEA *World Energy Outlook 2007 Alternative Policy Scenario* (APS). The APS takes into account those policies and measures that countries are currently considering and are assumed to adopt and implement, taking account of technological and cost factors, political context and market barriers (IEA 2007a).

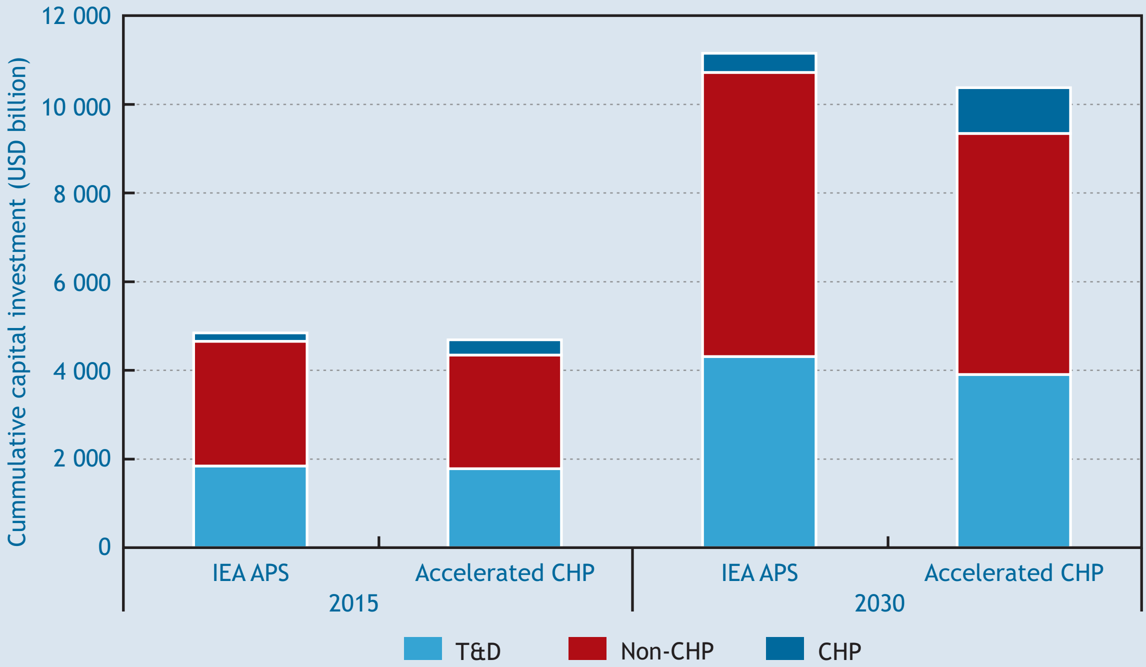
Results

The main results of the CHP benefits modelling are shown below.

Figure 13 compares the IEA APS with the Advanced CHP Scenario in relation to capital cost investment in the electricity sector, and breaks down the overall total investment requirement in new generation capacity (CHP and non-CHP), and new T&D system capacity.

9. For more information on the model and its assumptions, see Annex 1.

Figure 13 • Cumulative global power sector capital costs, 2005-2015 and 2005-2030



Source: IEA data and analysis.

There is a 3% reduction in overall costs by 2015 (USD150 billion), which mainly represent the reduction in investment required in new non-CHP generation capacity. By 2030, these cost reductions climb to 7% (USD795 billion). They are derived through:

- Savings in T&D network investment – since CHP generates electricity at the point of use, the requirement for T&D is reduced as CHP market share increases
- Savings through a significant reduction in non-CHP generation. The capital cost of new CHP investment is lower than the average capital cost of the central generation plant that is displaced (see Annex 1 for details of these and other assumptions). In addition, since greater use of CHP reduces T&D network energy losses, it also reduces the overall amount of generating capacity required to meet a given amount of demand.

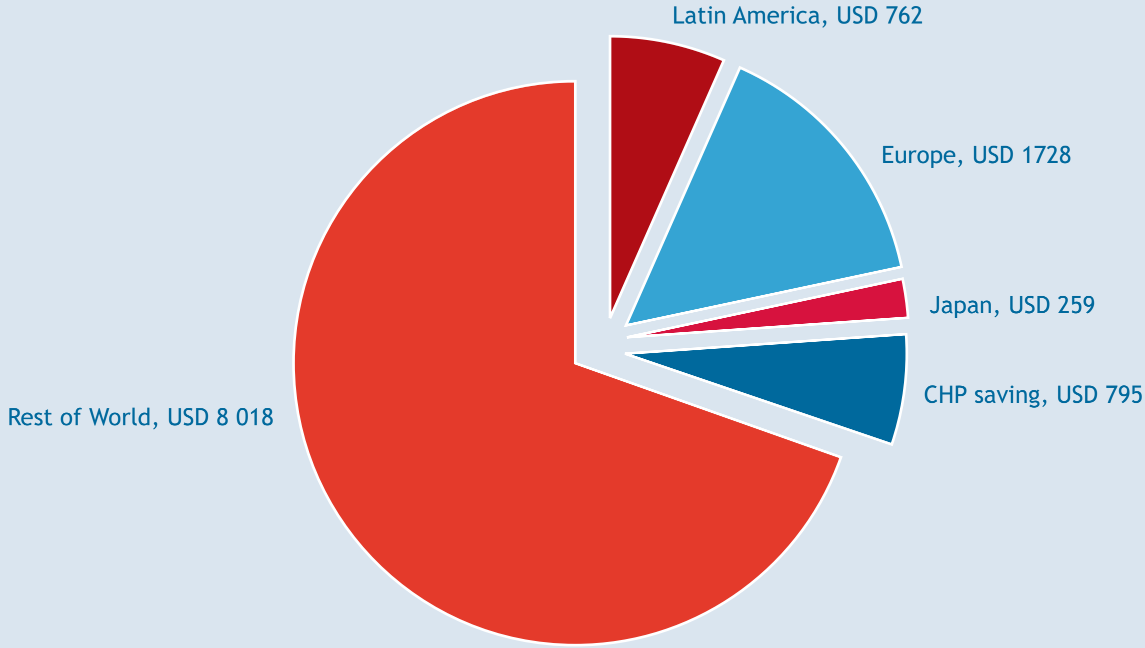
To put this 2030 capital cost saving into perspective, Figure 14 compares it to the total levels of power sector investment (including both generating capacity and T&D) projected for selected countries and regions by 2030.

Put another way, the projected saving of USD 795B by 2030 corresponds to (IEA 2007a):

- Projected investment in new US generation capacity required by 2030.
- Projected T&D investment required in Europe by 2030.
- Triple the projected total power sector investment required in Japan by 2030.

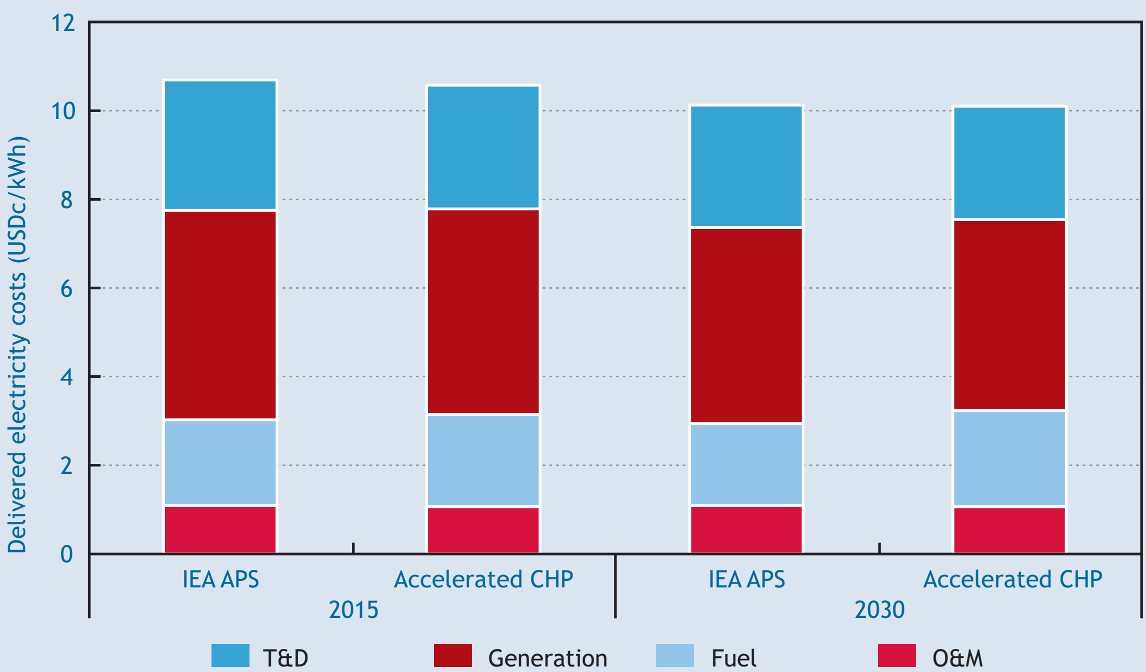
It is sometimes claimed that CHP, and other decentralised energy solutions, will result in an increase in energy costs for consumers. The impact of CHP market growth on delivered electricity costs was therefore assessed. Figure 15 compares delivered electricity costs to the end consumer for the two scenarios. The overall cost is again divided into the different constituents, including T&D system investments.

Figure 14 • Accelerated CHP capital cost savings (billions of USD) as a share of total power sector investment, 2005 - 2030



Source: IEA data and analysis.

Figure 15 • Delivered electricity costs, 2015 and 2030



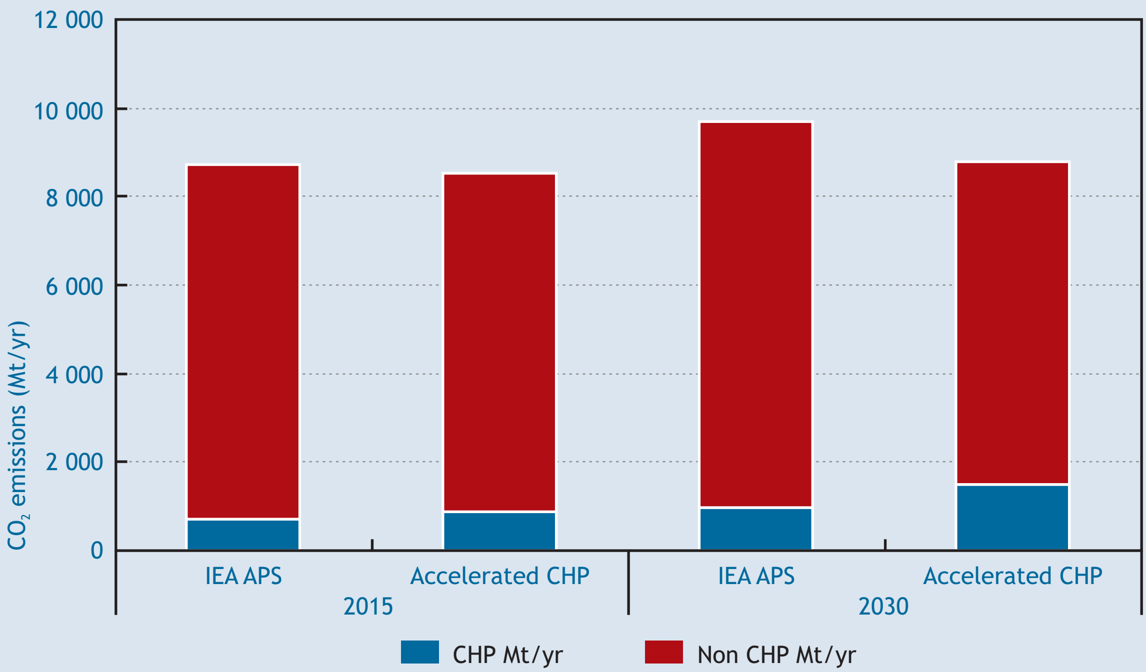
Source: IEA data and analysis.

Overall, there is a small reduction in delivered costs to end consumers in both time periods, 1.1% in 2015 and 0.3% in 2030. Thus it appears that increased use of CHP may not lead to increased electricity prices. Note that the fuel component of the delivered costs is higher in the ACS as some non-fossil and coal central generation is displaced by higher price natural gas. This is in turn offset by lower T&D and generation plant costs.

The analysis also shows that there is a reduction in fossil fuel use in power generation. These savings are in part offset by the fact that some new CHP in the ACS displaces nuclear capacity projected by the APS. In 2015, the fuel use in the ACS is 1.1% less than the APS; in 2030, the saving rises to almost 6% of total fossil fuel use in the 13 countries.

This reduction in fuel use leads to significant cuts in GHG emissions arising from new power generation. Figure 16 shows the comparison between the two scenarios for carbon dioxide emissions arising from the new power capacity.

Figure 16 • Carbon dioxide emissions, 2015 and 2030



Source: IEA data and analysis.

In 2015, in the ACS, CO_2 emissions arising from new generation are reduced by more than 4% (170 Mt / year), comparable to around 40% of the EU-25 and US Kyoto targets (the difference between 1990 Kyoto base year emissions and the respective targets), while in 2030 this saving increases to more than 10% (950 Mt / year).

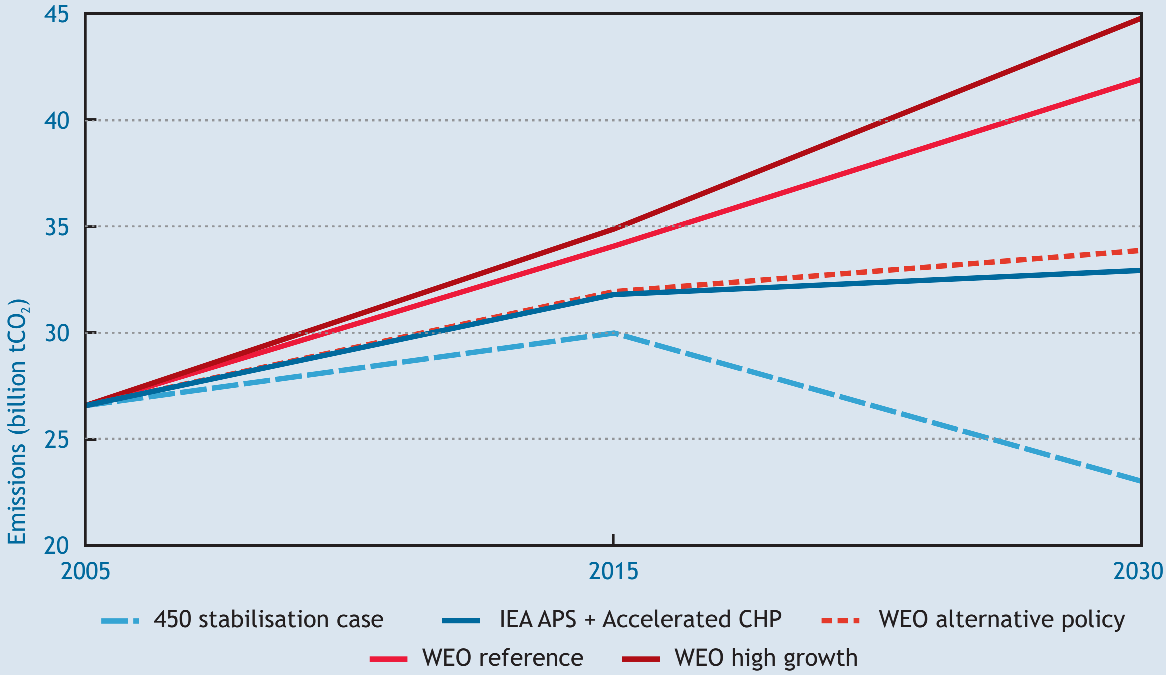
This is comparable to:

- The annual emissions arising from 140 GWe 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.

Figure 17 gives an indication of the contribution that CHP can make to achieving global climate stabilisation.

The World Energy Outlook APS already makes an important start toward bridging the gap, and therefore includes a degree of CHP market growth above and beyond what exists today. The Accelerated CHP Scenario demonstrates a possible additional contribution that CHP can make towards stabilisation.

Figure 17 • Contribution of CHP to a 450 ppm stabilisation scenario



Source: IEA data and analysis.

Section 4 • Next Steps

This report provides policy makers with a projection at the global level of the potential benefits that a more deliberate investment in CHP could deliver. However, it is only one piece of the puzzle.

The conclusions in the Executive Summary beg the question: "why is there not more CHP/DHC if the economic justification is so strong?" One of the key challenges is that many projects look favourable "on paper"; that is, when analysed in isolation from existing market and regulatory practices. However, in practice, the adoption of these technologies has historically been limited by important barriers, including:

- lack of integrated urban heating / cooling supply planning;
- electricity grid access and interconnection regulations;
- lack of knowledge about CHP benefits and savings; and
- the lack of an agreed methodology to recognise energy saving and environmental benefits.

A few countries cited in this report have been successful in increasing the use of CHP and DHC by investing in a comprehensive set of policies designed to overcome market barriers and allow them to compete equally in the marketplace. These countries and others will need a closer look as policy makers attempt to find solutions and models that are suitable for their unique circumstances.

The IEA International CHP/DHC Collaborative is working on these issues (see box). This report is the first of two; the second report will be published later in 2008 and will include lessons learned from policies summarized from a series of case studies covering key energy, environment and utility regulatory/planning approaches that have been taken in different countries. The next report will also include a list of priorities for different regulators that are interested in implementing more advanced policies.

The International CHP/DHC Collaborative

The International CHP/DHC Collaborative was launched in March 2007 to help evaluate global lessons learned and guide the G8 leaders and other policy makers as they attempt to assess the potential of CHP and DHC as energy technology solutions.

The Collaborative includes the following activities:

- collecting global data on current CHP and DHC installations
- assessing growth potentials for key markets
- developing country profiles with data and relevant policies
- documenting best practice policies for CHP and DHC
- convening an international CHP/DHC network, to share experiences and ideas

Participants in the Collaborative include Partners, mentioned in the acknowledgments, as well as Collaborators, a group of over 40 government, industry and non-governmental organizations that provide expertise and support. The Collaborative Network, the larger group that is informed about meetings, publications and outreach, has almost 300 participants.

If you are interested in participating in the Collaborative or want more information, please visit www.iea.org/G8/CHP/chp.asp.

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Annex 1 • CHP Potential Modelling - Summary of Methodology and Assumptions

As part of the IEA CHP Collaborative, the IEA has developed a model to estimate the potential growth for CHP[10] for the G8+5 countries in 2015 and 2030.

Economic Potential in a Pro-CHP Policy Environment

CHP applications are typically attractive when analysed "on paper"--that is, in isolation of various market, regulatory and institutional barriers that exist. As such, CHP has only been able to achieve roughly 10% of total global electricity production.

The purpose of this analysis was to investigate the magnitude of additional energy savings and environmental benefits that would be associated with increased use of CHP. To complete this analysis, it was assumed that the 13 countries were put on a path similar to that of countries (for example Denmark, the Netherlands, or Finland) that have been able to achieve significantly higher levels of CHP in their energy mix. Therefore, the principal assumption was that each country adopts a pro-CHP policy / regulatory regime (for example removing barriers to CHP and introducing policy / regulatory incentives in favour of CHP) that corresponds to the level of growth that has been seen in these three markets.

The model incorporates more aggressive demand-side energy efficiency and renewable energy assumptions by utilising the IEA's *Alternative Policy Scenario* as the point of comparison against an advanced CHP future. As such, the model assumes CHP competes along with other expected energy solutions, albeit with a more aggressive policy framework than exists at the current time.

This approach is based on an *economic* potential for CHP growth, in contrast with *technical* potential. There is likely to be a much higher technical potential for CHP than we conclude here, perhaps exceeding 100% of electricity demand in some cases. However, although there is sufficient heat and cooling demand to enable much of the technical CHP potential that exists, it was decided that the penetration achieved in the Northern European countries was a more realistic, and achievable proxy for comparison.

Heating and Cooling Demand – the Basis of the Methodology

The level of CHP development in a country depends on heating and cooling demand in the industrial, commercial and residential sectors. This demand was used as the basis for the approach taken to analyse CHP potentials: to estimate, taking into account different national circumstances, the proportions of current and future heating / cooling demand in each of the 13 countries that could be reasonably served by CHP.

The model therefore uses inputs of current and projected heating demand (industrial, commercial and residential sectors) and cooling demand (commercial and residential sectors). For each, there is a share which is captured by CHP. For example, to estimate the potential for CHP in the industrial sector in a country in 2015, the following steps are involved:

1. Identify IEA industrial energy demand for 2005.
2. Subtract out the portion used for electricity.
3. Multiply the remainder by .8 to account for the portion of fuel used as feedstocks.
4. Adjust to allow for existing heat demand already met by CHP.
5. Estimate the share of remaining heat demand that can be met by CHP between 2005 and 2015.

10. Includes all CHP applications, including industrial and commercial buildings CHP, district heating-based CHP and micro-CHP residential technologies.

6 Apply an average power:heat ratio corresponding to industrial CHP in the period up to 2015.
7 Calculate the CHP electricity generation arising from step 3.
8 Identify the projected growth in heat demand between 2005 and 2015.
9 Estimate the share of this new heat demand that can be met by CHP between 2005 and 2015.
10 Same as step 4 above.
11 Calculate the CHP electric generation arising from step 7.
12 Sum the outputs of steps 5 and 9.

This process is repeated for the commercial and residential sectors to derive a total 2015 electric generation based on CHP. The CHP market share of total projected portion of power generation is then calculated, based on projections from the IEA 2007 *World Energy Outlook*.

The same process is used to derive CHP potentials for 2030.

Other important points relating to the methodology and assumptions are as follows:

- All heating / cooling demand and national electric generation base data and projections are derived from IEA sources.
- Base year CHP data for the 13 countries is based on IEA data collection, and includes data compiled and harmonised from several sources, including Eurostat in Europe and other government and industry data sources.
- While separate heating and cooling data is available for the commercial and residential sectors, it is not available for the industrial sector where industrial energy (not heat) demand data only is available. To allow for use of energy feedstocks in industrial processes, a conversion factor of 0.8 has been used to convert energy demand to heat demand.
- Projected power:heat ratios have taken account of the different technologies used in different sectors. We have assumed higher electrical efficiency CHP use in industry (a P:H ratio of 0.9 in most cases) than in the residential and commercial sectors (a ratio of 0.7 for heating and 0.8 for cooling). Occasional adjustments of these assumptions have been made on a country by country basis.[11] For CHP development to 2030, slightly higher P:H ratios have been used to reflect improvements in the efficiency of CHP systems.
- Different assumptions were made on a country-by-country basis to take into account different national parameters, including climatic differences (for example, CHP with cooling is more likely to be applied in Brazil and India than in Russia). Also, the pattern of industrial development has been assumed to be more energy-intensive (and therefore more suitable for CHP) in non-OECD countries in the future.
- Almost no data is available for current or future CHP in South Africa. Current indications are that the current CHP market share is very small. To assess the potential for CHP, an average CHP share of new generation has been derived from the data for China, India, Brazil and Mexico, and applied to projected electric generation growth in South Africa.

Benefits Modelling

The second step for the IEA CHP Collaborative involved modelling benefits of developing the CHP potential in the G8 + 5 countries.

Methodology and Model Used

The World Alliance for Decentralized Energy (WADE) Economic Model was used as a basis to assess the benefits associated with the CHP Potential identified for the G8+5 countries.[12] The WADE Model was deemed to be a suitable tool for this analysis, as it incorporates the system-level heat benefits of CHP, as well as the costs of building electricity networks to connect centralised and CHP power plants.

11. For example, in China, lower Power:Heat ratios were used to allow for the fact that a high proportion of CHP will be based on coal-fired steam turbines.

12. For more information on the WADE model, see www.localpower.org/nar_model.html.

The WADE Model has been used and applied by, among others, the European Commission and the governments of: Australia, Canada, Germany, Ireland and the UK.

In summary, the model "builds" new power generation, according to user-defined preferences, to meet future electricity demand growth and to replace some capacity that already exists today but will be retired in the future. The model thus allows the user to determine different power generation mix scenarios to meet future energy demand. The model then produces outputs that compare the different scenarios in economic and environmental terms.

For this analysis, the model was programmed to 'build', and compare, two scenarios: the Accelerated CHP Scenario described above and the IEA World Energy Outlook 2007 Alternative Policy Scenario (APS). The basis of the APS is to take into account those policies and measures that countries are currently considering and are assumed to adopt and implement, taking account of technological and cost factors, the political context and market barriers (IEA 2007a).

The model outputs include the following benefits streams:

- total investment costs (including generating capacity and T&D networks) needed to meet future energy demand
- total delivered costs of electricity to end consumers
- CO_2 emissions reductions
- reductions in fuel use

Inputs, Sources and Basic Assumptions

The WADE Model requires a range of inputs on the existing electricity system, and assumptions on its future development. These were based on the IEA data and projections where possible, but in some cases other sources were used, or separate assumptions made. These assumptions are detailed below.

Existing Capacity and Generation

- Centralised Generation Technologies – WEO 2007 (adjusted for the 13 countries)
- CHP Technologies – IEA CHP Collaborative database

Pollution Emission Factors

- Based on the Gemis database (version 4.42) of the Öko-Institut[13]

Heat Rates and Efficiencies

- Based on previous WADE model applications

Cost Data

- Technology Costs – IEA sources, including the *Electricity Information 2007, Projected Costs of Generating Electricity* (IEA 2005 Update)[14]
- Future Technology Cost Development
- 2005 to 2015 – Projections from previous WADE model runs
- 2015 to 2030 – No change
- Current Fuel Prices – Electricity Information 2007
- Future Fuel Prices – WEO 2007
- Return on capital – 10%

13. Oeko Institut. «Global Emissions Model for Integrated Systems (GEMIS),» Version 4.2. 2007, http://www.oeko.de/service/gemis/en/index.htm.

14. IEA, Nuclear Energy Agency, and Organisation for Economic Co-operation and Development, (2005), Projected Costs of Generating Electricity 2005 Update, OECD/Paris.

- Financing period – 20 years
- T&D investment costs – WEO 2007

Electricity System Properties

- T&D losses – *Electricity Information 2007* (IEA 2007)
- Demand growth – WEO 2007 (adjusted for G8+5)
- Central generation capacity margin – 15%; T&D capacity margin – 15%; CHP capacity margin – 10%

Future Capacity and Generation Growth

- Centralised technologies – WEO 2007, Alternative Policy Scenario (adjusted for the 13 countries)
- CHP technologies – IEA CHP Potential modelling
- CHP split between different fuels – Based on projections for the shares of different fuels for CHP in 2015 and 2030 for the 13 countries

Capital Cost Assumptions

Technology	2005 cost (USD/kW)	Change 2005 -2015	Cost 2015 – 2030 (USD/kW)
Coal ST	1 350	0%	1 350
Oil ST	1 340	0%	1 340
Gas CCGT	570	0.5%	627
Nuclear	2 250	1.0%	2 718
Wind	1 500	-1.0%	1 239
Solar	3 600	-5.0%	1 358
Hydro-electric	2 500	0%	2 500
Biomass	1 600	-2.0%	1 090
Gas CHP	1 324	0%	1 324
Coal CHP	2 766	0%	2 766
Biomass CHP	2 568	-2.0%	1 750
Gas micro-CHP	2 500	0%	2 500

Non-CHP

Transmission network costs: USD 346 per kW

Distribution network costs: USD 804 per kW

CHP

Transmission network costs: USD 0 per kW

Distribution network costs: USD 804 per kW

Additional Assumptions

Some other assumptions had to be made, because not all data could be incorporated into the Model directly, and not all required data were available. These were:

- The WEO 2007 does not provide data on the 13 countries, nor was all data available for the individual countries. For this reason the WEO projections for the world were adjusted, based on the current share of generation for this group of countries. It was assumed that this remains constant until 2030.

- The CHP Potential outputs do not split the future CHP capacity by fuel type. Using the existing share of various fuels in the 13 countries, assumptions were made about the fuel split in 2015 and 2030. The rate of change in fuel use over the period modelled was assumed to be linear.
- The WEO 2007 does not provide projections for retirement of existing plants, an important input for the WADE Model. The rate of retirements was therefore based on previous analyses, including the United States and China.

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