International Energy Agency

Co-generation and Renewables

Solutions for a low-carbon energy future

INTERNATIONAL ENERGY AGENCY

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- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
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Introduction

Co-generation or Combined Heat and Power (CHP) is the simultaneous generation of both electricity and heat from the same fuel, for useful purposes. The fuel varies greatly and can include coal, biomass, natural gas, nuclear material, the sun or the heat stored in the earth.

This paper fills a gap in the energy discussion by focusing on two low-carbon options: co-generation and renewables and also on heat. The need for a holistic approach to these three topics arises from a realisation that strong synergies can exist between the three. The efforts to constrain greenhouse gas emissions and concerns over security of supply of fossil fuels have led to increased attention and policy support for renewable energy over the past decade. Shares of renewable energy (RE) supply have risen over the past years and projections show the trend is likely to continue as countries transition to a low-carbon economy. Renewable energy is one of the key solutions to our energy challenges. However, transitions take time, especially when they are on the scale needed to re-invent our energy system. Even though in the coming decades the share of renewables will rise, fossil and other alternative fuels will still play a major role. For that reason, it is important to use these fuels as efficiently as possible. Co-generation offers the best of both worlds:

- Co-generation is a proven energy-efficient technology.
- Co-generation can accelerate the integration of renewable energy technologies.

In many instances co-generation and renewables complement each other. Several renewable technologies can be operated in co-generation mode. These include biomass, geothermal and concentrating solar power (CSP). Co-generation can assist in balancing electricity production from variable renewables. Some of the technologies that will be used for balancing renewables will invariably be fossil-based. By increasing the efficiency of the latter technologies, co-generation represents a low-carbon balancing solution. While electricity supply is a crucial aspect of the energy debate and will continue to remain as such, decision makers increasingly realise that heat supply is a sizable part of the energy system. If the system is to be decarbonised, changing the heat supply will also need to be considered. Both co-generation and renewables are technologies that are relevant to heat supply.

Why read this paper?

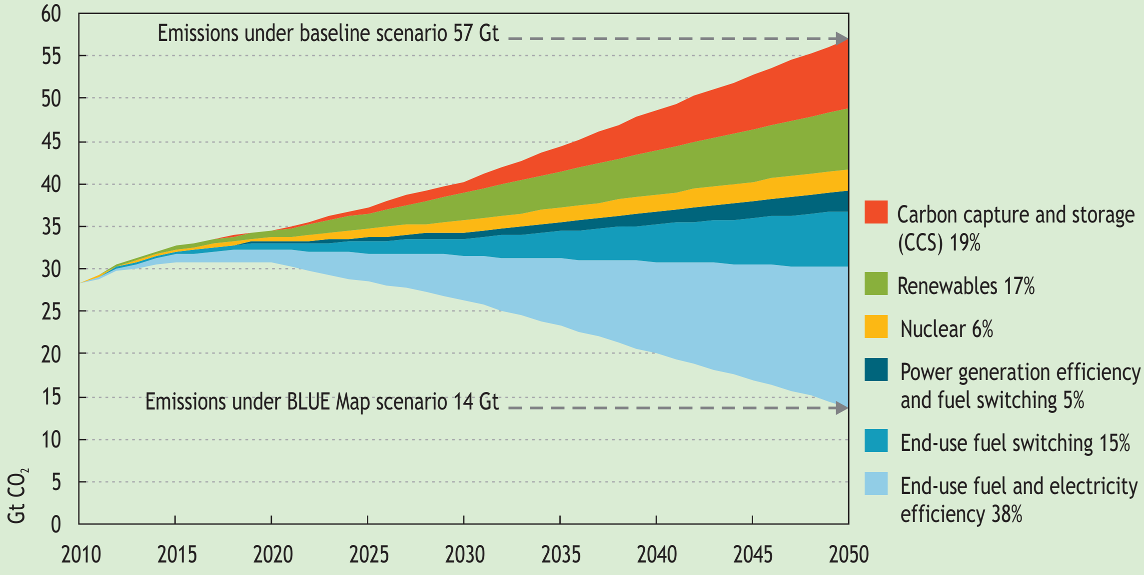
- It stresses the low-carbon benefits of both co-generation and renewables as stand-alone technologies.
- It demonstrates how, taken together, renewables and co-generation make a strong case for low-carbon energy solutions, by paying attention to:
  - The "double low-carbon benefit" of using renewable energy in co-generation mode
  - The potential of co-generation to contribute to lowering the carbon footprint associated with balancing variable renewable electricity generation
- It explains the need for more attention for the topic of heat in the energy debate. Heat represents 37% of total final energy consumption in OECD countries and 47% globally.
- It supports the implementation of appropriate policy incentives for both co-generation and renewables.

Co-generation and Renewables: Energy-efficient Supply of Low-carbon Heat and Electricity

Co-generation (as a vector of energy efficiency) and renewables each possess their own set of low-carbon benefits. Coupling co-generation and renewables makes for a very strong proposition since it leads to the supply of both low-carbon electricity and low-carbon heat. In the case of co-generation plants fuelled by renewable energy sources, the low-carbon benefits of the heat are obvious since they derive from the renewable nature of the fuel. However, these also apply in the case of plants fuelled by other types of fuel. Such plants produce excess heat alongside electricity. When this heat, which is an unavoidable by-product, is used to satisfy an existing heat demand carbon dioxide (CO_2) emissions are reduced overall, through more efficient use of the fuel.

Energy efficiency and renewables are both important if a sustainable future is to be realised. This is well illustrated in *Energy Technology Perspectives 2010 (ETP 2010)*, where the current trend represented by the Baseline Scenario (Figure 1) is described as unsustainable. In contrast, when appropriate actions are taken, the BLUE Map Scenario[1] is described as more sustainable. There are a number of key technologies that can help bridge the gap between these two courses of action taken from *ETP* 2010. Both energy efficiency and renewable energy can contribute to the transition from an unsustainable energy path to a sustainable one. Co-generation is considered as one option that contributes substantially to energy efficiency, including through district heating and cooling networks. Such contributions are embedded in Figure 1 within the three lower wedges, together accounting for 58% of total contributions.

Figure 1 • Key technologies for reducing CO_2 emissions



Source: IEA, 2010(h).

1. The BLUE Map Scenario assumes that global energy-related CO_2 emissions are reduced to half their current levels by 2050. The scenario examines ways in which the introduction of existing and new low-carbon technologies might achieve this at least cost. The BLUE Map Scenario is consistent with a long-term global rise in temperature of 2°C to 3°C but only if the reduction in energy-related CO_2 emissions is combined with deep cuts in other greenhouse-gas emissions. It also brings energy security benefits in terms of reduced dependence on oil and gas, and health benefits as air pollutant emissions are also reduced.

According to *ETP 2010*, for electricity generation "the use of CHP approximately triples in the BLUE Map Scenario in absolute terms between 2007 and 2050. The share of CHP in power generation increases to 13% over this period, up from 10% in the Baseline Scenario." The contribution of renewables accounts for 17% of the total CO_2 reductions under the BLUE Map Scenario. One technology by itself will not bring about the dramatic changes that are needed to resolutely reform the energy system. Co-generation and renewables, both low-carbon solutions, will be part of the solution.

This chapter stresses:

- How co-generation contributes to energy efficiency.
- The importance of renewable energy.
- The need for proper consideration of heat in the energy debate, especially from the perspective of what co-generation can offer in this often neglected but very important form of energy.

The economic and environmental benefits of co-generation

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. Co-generation represents a proven technology to achieve that goal.

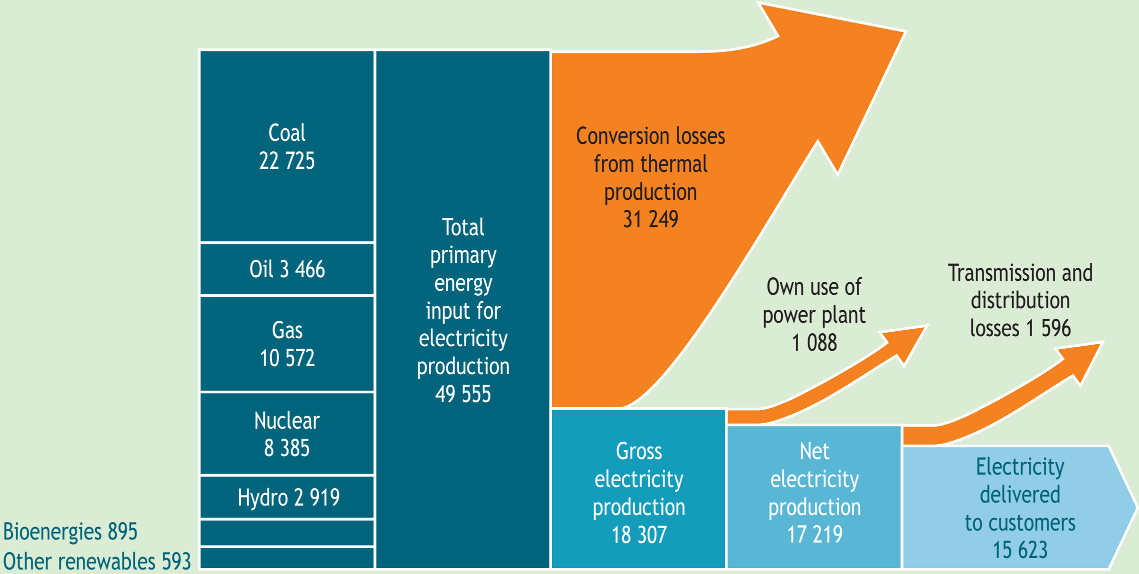
The average global efficiency of fossil-fuelled power generation has remained stagnant for decades at 35% to 37%. Technologies already exist today to bring the generation fleet closer to 45% efficiency and the reasons why efficiencies have not edged closer to the 45% mark are not dealt with in this report. Going significantly beyond 45%, for a large part, does not reflect a lack of incentive to research and develop new technologies to extract energy stored in fossil fuels in more efficient ways. It has more to do with the intrinsic, theoretical constraints on the conversion of heat into electricity. Notwithstanding gains that could come from research efforts over time, power generation efficiency will plateau below the level of overall efficiency that the best co-generation plant can achieve. Co-generation allows 75% to 80% of fuel inputs, and up to 90% in the most efficient plants, to be converted to useful energy. The two-thirds of input energy lost globally in traditional power generation (Figure 2) represent significant missed opportunities for savings on both energy costs and CO_2 emissions. Implementing co-generation does not, in itself, increase the power supply for a given plant; rather it increases overall energy efficiency by supplying useful heat alongside useful electricity. By making more efficient use of fuel inputs, co-generation allows the same level of end-use energy demand to be met with fewer energy inputs. When these energy inputs are fossil-based, this leads not only to less reliance on these CO_2-generating fuels, but also preserves such exhaustible materials for applications where they can less easily be substituted. Co-generation is, thus, a low-carbon energy solution.

Box 1 • Co-generation delivers a range of policy objectives

As previous IEA reports have highlighted (IEA, 2009(e); IEA, 2008(a)) co-generation is attractive to policy makers and private users and investors because it delivers a range of energy, environmental and economic benefits, including:

- dramatically increased energy efficiency;
- reduced CO_2 emissions and other pollutants;
- increased energy security through reduced dependence on imported fuel;
- cost savings for the energy consumer;
- reduced need for transmission and distribution networks; and
- beneficial use of local energy resources (particularly through the use of waste, biomass and geothermal resources in district heating and cooling systems), providing a transition to a low-carbon future.

Figure 2 • Energy flows in the global electricity system (TWh)

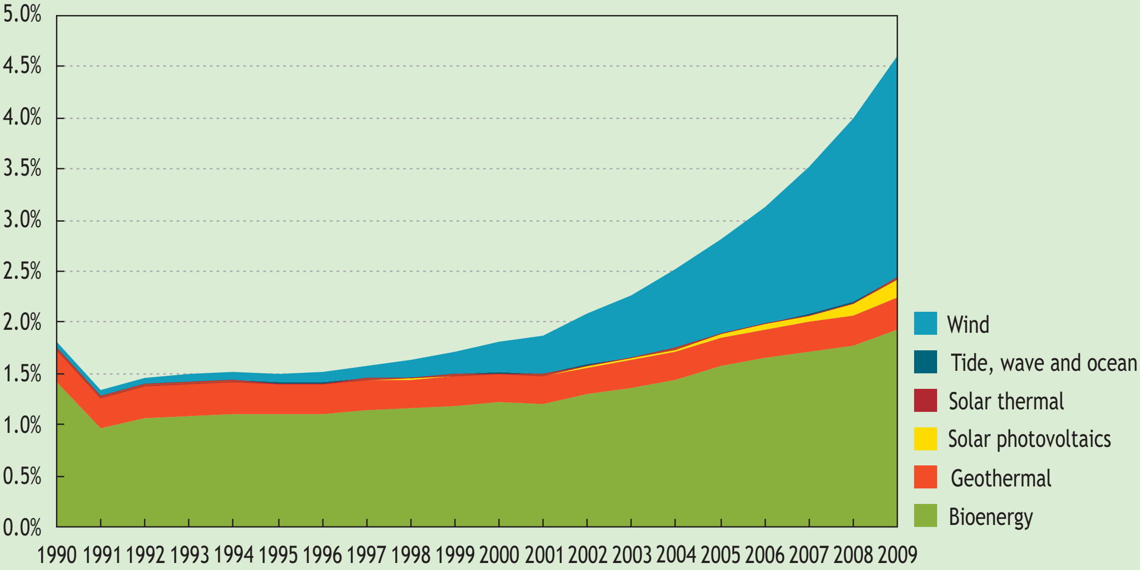


Source: IEA, 2008(a).

The economic and environmental benefits of renewables

According to the IEA, an energy revolution is needed to achieve a 50% reduction of global CO_2 emissions relative to current levels by 2050 — a target that is deemed a condition for a long-term global rise in temperature of 3^{0}C maximum. Renewable energy will have to play a crucial role in this revolution. Growing interest for renewables from governments, as evidenced by the introduction of supporting policies and renewable energy targets, has led to significant development and deployment of renewable energy over the past two decades, particularly in the power sector (Figure 3).

Figure 3 • Share of non-hydro renewables in electricity generation (TWh) of IEA countries 1990-2009



Note: Total electricity generation was 7440 and 9960 TWh in 1990 and 2009 respectively.

Renewable energy is any energy source that derives directly or indirectly from natural processes related to sunlight, heat stored in the earth or gravitational forces and that is constantly, naturally replenished. As long as the rate of extraction of this energy source does not exceed the natural rate of replenishment, then the resource is sustainable. Renewable electricity can be produced from wind energy, solar energy through photovoltaics (PV) and concentrating solar power (CSP), hydro energy, ocean energy and bioenergy. Renewable heat sources include geothermal heat, solar thermal heat (low temperature heat from flat panels and high temperature heat from concentrated solar power) and bioenergy. Biofuels can supply the transport sector.

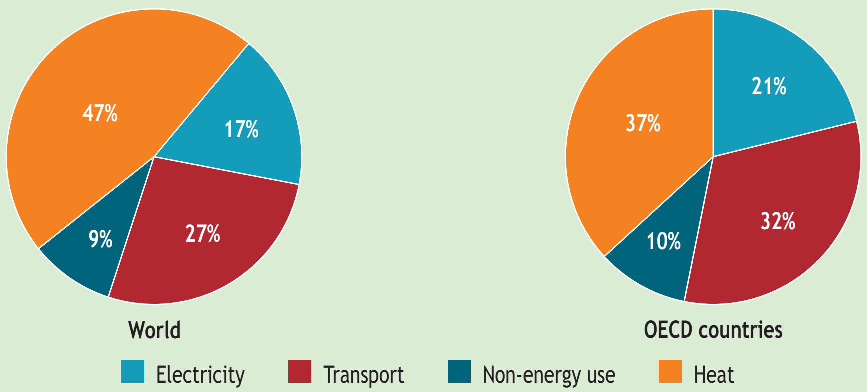
Technological progress and policy support have led to significant development and deployment of renewable energy. Despite progress, a number of challenges still need to be overcome in order to foster the necessary growth of renewables. Under current market conditions it will be crucial to improve the policy framework for renewables in order to bridge the competitiveness gap between renewables and traditional alternative energy technologies. It will also be important to champion continued and sustained effort in research, development and deployment (RD&D) for renewable energy technologies in order to increase productivity and reduce costs. Finally, rapid deployment of renewables raises important system integration issues that must duly be taken into account. A number of options and technologies, including smart grids, exist in order to increase the flexibility of electricity systems and allow the integration of larger portions of variable renewable electricity.

So far, most attention has been focused on renewable energy for electricity. However, IEA analysis shows that the global share of heat in total final energy consumption in 2008 was much greater than that of transport, electricity and non-energy use. More analysis on technologies and policies must be devoted to renewable heating and cooling which represent an enormous untapped potential in many countries. Co-generation technology offers the potential of supplying both renewable electricity and renewable heat.

Spotlight on heat

While "energy" is a key overarching theme of the energy and climate change debate, in practice, most of the attention focuses on electricity and transport. Increasingly, even transport is folded into electricity because of increased emphasis on electric vehicles. Despite the fact that its demand dominates all other energy uses, heat is largely overlooked. Heat represents a sizable part of (final) energy consumption (Figure 4), both globally and in countries belonging to the Organisation for Economic Co-operation and Development (OECD).

Figure 4 • Shares of total final energy consumption broken down into electricity, transport, heat and non-energy use



Notes: "Non-energy use" covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel. For example, oil used to make plastics would be classified as non-energy use. Electricity use in transport is subtracted from final energy use in transport. Heat generated by auto producers for their own use will not be reported or registered, and therefore is not represented. Data on electricity use for heating in the industry sector and other sectors are unavailable, and therefore have not been taken into account.

Fuel mix for heat

In OECD countries, heat production is dominated by fossil fuels with 50.5% of heat being produced by gas (Figure 5). About one-quarter of heat is produced by oil; coal and combustible renewables and waste each represent a similar share of nearly 10%. In OECD countries, 4.4% of heat comes from commercial heat — *i.e.* heat that is sold including heat distributed by district heating networks to residential buildings — whereas geothermal and solar heat amounts to a negligible share of 0.6%. Worldwide similar trends are observed, albeit in different proportions: the top three fossil fuels still account for more than two thirds of the fuel mix in meeting final heat energy consumption.

Figure 5 • Fuel mix for generating the heat component of total final energy consumption

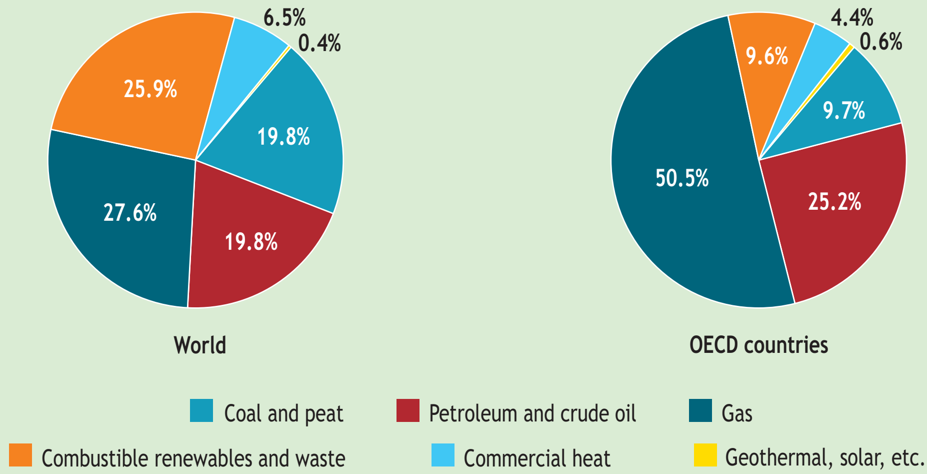


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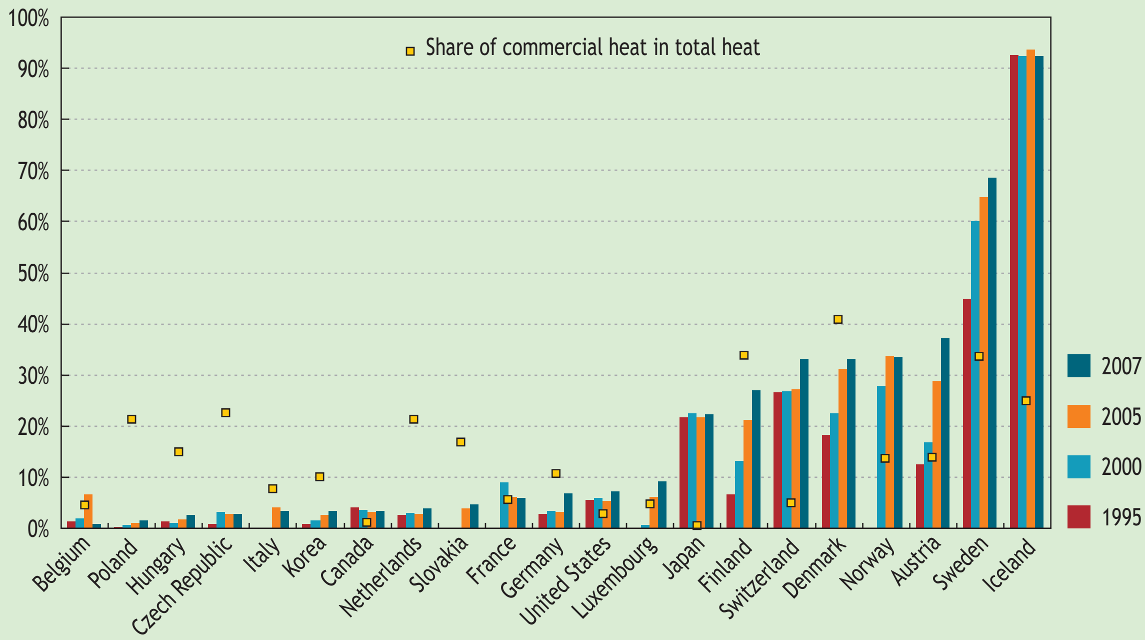
Figure 6 • Development of shares of renewables in the generation of commercial heat in selected OECD countries



Note: The term "commercial heat" refers solely to heat produced in a heat or co-generation plant and then sold through a network to industrial facilities, households or commercial establishments.

Commercial heat can be produced from several renewable energy sources including combustible renewable materials, solar energy and/or geothermal energy. The share of commercial heat consisting of renewable heat is not distinguished in Figure 5. Figure 6 shows the development of shares of renewable heat in commercial heat for selected OECD countries. During the period 1995 to 2007, Austria, Denmark, Finland and Sweden showed remarkable increases – between 15 to 24 percentage points – of renewable heat as a share of commercial heat. In 2007, Austria reported a high share of bioenergy used in co-generation and heat-only plants. Denmark indicates a high share of bioenergy including renewable municipal waste (MSW) and geothermal energy for commercial heat. It is the only country to report (low temperature) solar thermal energy supply to commercial heat. In Finland and Sweden, commercial renewable heat is dominated by the use of bioenergy. In Norway, renewable MSW takes the lion share in renewable commercial heat. Iceland is known for its high share of geothermal heat used in district heating networks; the share of renewable commercial heat in Iceland has remained constant for decades and can only increase marginally due to the existing high share.

Sectoral use of heat

Heat represents a sizable part of total final energy consumption; the heat segment itself can be further broken down into the sectors that use heat (Figure 8). Industry is the largest heat-consuming final sector with shares of nearly 43% globally and 44% in OECD countries. The residential sector and the commercial and public services sector are often combined into one category, described as the buildings sector. With this aggregating, the buildings sector is responsible for 50% of final energy use for heat worldwide and 52% of final energy use for heat in OECD. The high share of final energy use for heat in the residential sector on a global level is likely to be influenced by large amounts of traditional biomass used at low efficiencies for cooking. Though still marginal, the concept of absorption cooling uses heat as input for achieving cooling in buildings (Box 2).

Unlike electricity, heat cannot be transported efficiently over large distances. As a result, it must be generated close to where it is consumed. Another challenge is that heat requirements reflect a wide range of temperatures and scales. While buildings are comfortable at 20^{o}C, some large industrial processes require heat in excess of 400^{o}C. Heat demand segments are often distinguished into low temperature heat demand for space heating and domestic hot water in the buildings and agricultural sectors, and high temperature heat demand in the industrial sector. Demand for heating in buildings varies widely with the design, age and materials of the building, as well as with the season and time of day. Industrial heat demand does not always require high temperatures, but is known for having a wide diversity with respect to temperature levels needed for many different types of industrial processes.

Meeting heat demand is a question of both quantity and quality of heat. Different temperature levels in both heat demand and (renewable) heat supply can result in a mismatch between the quality of heat supplied and the heat required, even though the quantity of heat may be an appropriate match. The characteristics of the heat demand and supply can significantly influence the suitability and financial viability of heat-generating technologies, including renewable-fuelled technologies which tend to supply heat at lower temperatures.

According to the estimated industrial heat demand shown in Figure 9 the chemical, non-metallic minerals, and basic metal industries have the highest temperature demands. In total, high temperature demands make up 43% of the total demand while medium and low temperature demands correspond to 30% and 27% of total demand. Data in Figure 9 are based on extrapolating industrial heat demand in Germany to other European countries. So far, little data is available on industrial heat demand and shares of temperature levels in other countries. In order to assess potential for renewable heat in industrial processes, more information is needed on heat demand in a wide variety of countries.

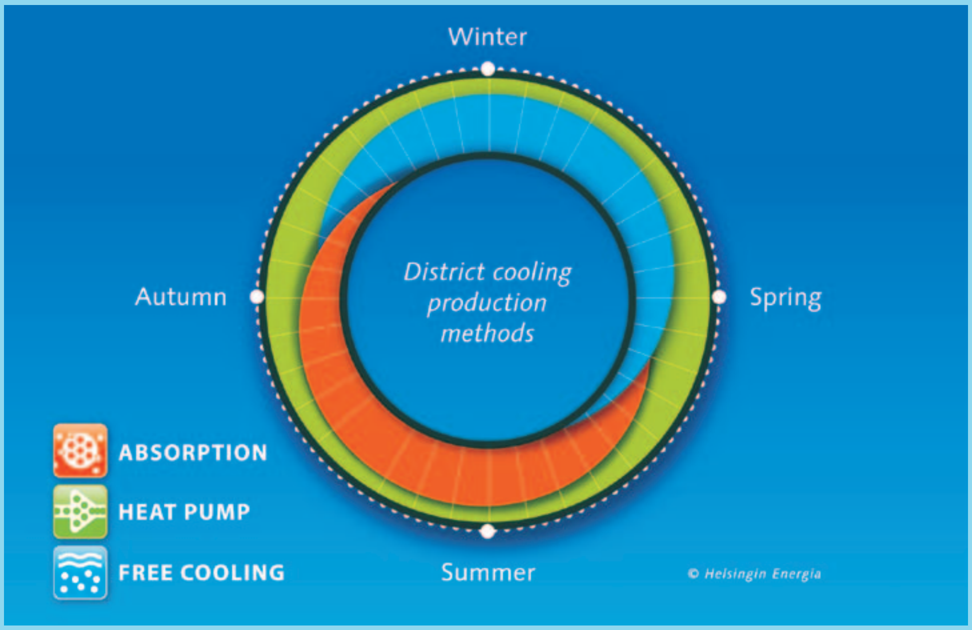
The size of the heat demand, as well as the variety in the nature and use of heat, demonstrates the value of co-generation systems. Often, the heat component of co-generation is thought of as having a lesser value than the electricity component. Considering that heat represents such large shares of total final energy consumption (37% in OECD countries and 47% globally), the value of this available heat is clearly underestimated. The need for low-carbon energy makes co-generation and renewables an obvious combination.

Box 2 • Absorption chilling: using heat for cooling

Most cooling systems are based on a process in which a fluid (called a refrigerant) is run through a compressor to raise its pressure. Upon release from the compressor, the fluid suddenly expands and its temperature drops, thereby cooling the surrounding air. The expanded refrigerant is then compressed again, thus closing the cycle. The compressor is a mechanical piece of equipment generally driven by electricity.

Absorption cooling also cools by expansion of a refrigerant, but the technology uses heat energy to raise the pressure of the refrigerant, thereby eliminating the need for electricity to drive the compressor (UK DECC, 2010). Absorption cooling is already in commercial use and is particularly suitable in places where excess heat is available for which there is not much use (Figure 7). By making use of available excess heat, absorption cooling can help meet increasing cooling needs without much additional electricity consumption or CO_2 emissions.

Figure 7 • Absorption cooling: part of the district cooling technology mix in Helsinki



Note: Free cooling refers to the use of cold seawater.
Source: Helsinki Energy

Figure 8 • Shares of final energy consumption for heat by sector

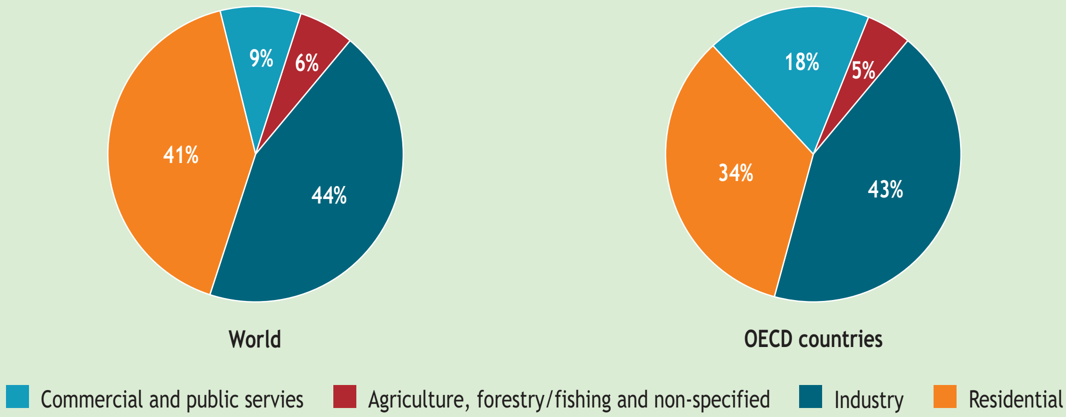
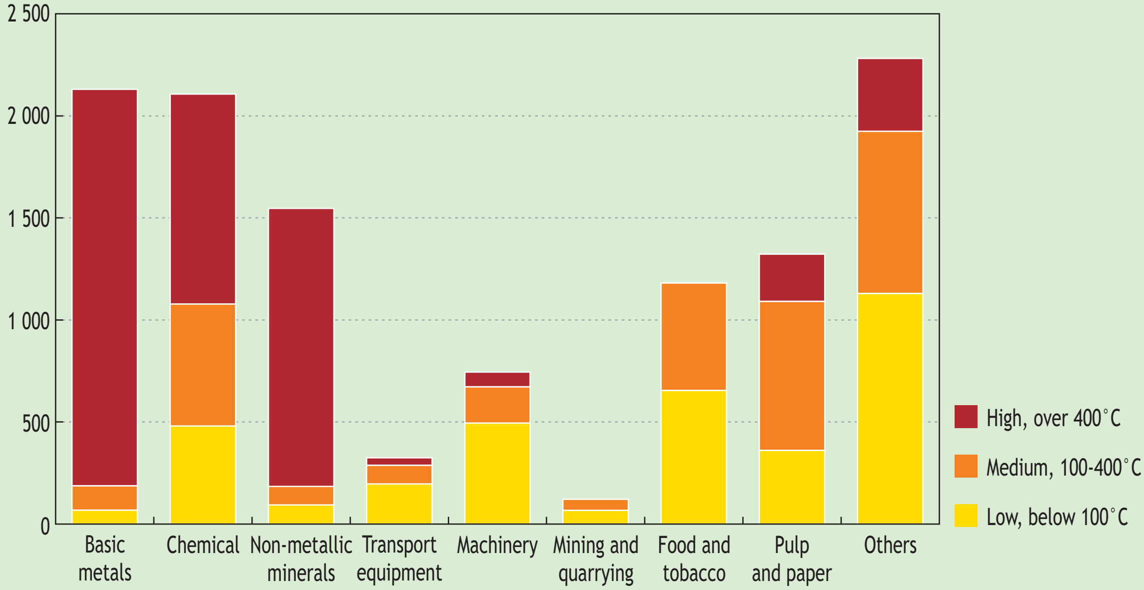


Figure 9 • Estimated industrial heat demand (PJ) by sector and temperature level in 32 European countries



Source: Eco HeatCool Work Package 1, The European Heat Market, 2003, on the basis of applying trends for German industry to IEA balances for target region: www.euroheat.org/Files/Filer/ecoheatcool/documents/Ecoheatcool_WP1_Web.pdf.

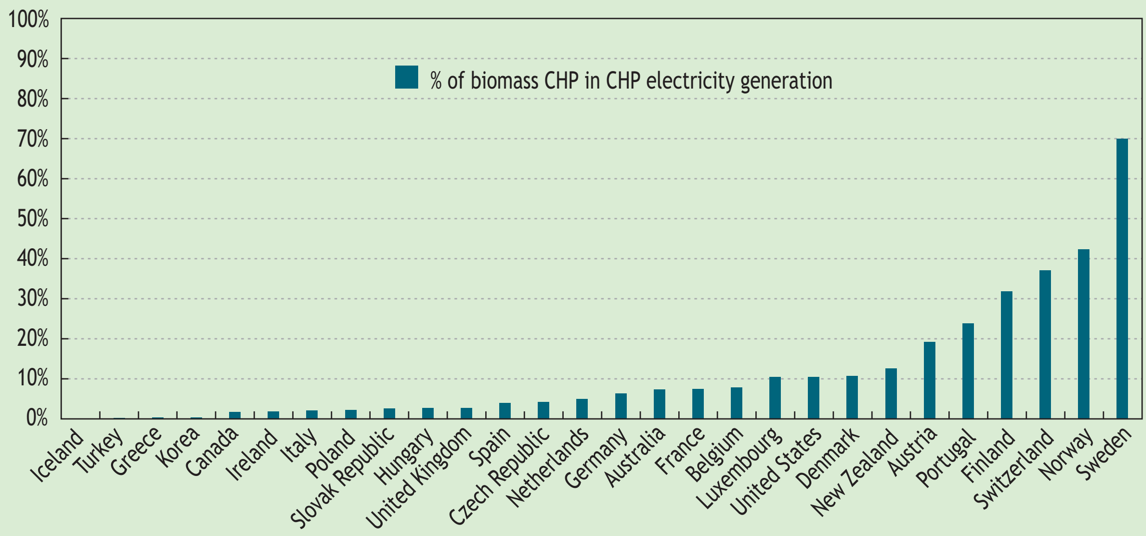
Renewable Co-generation Technologies

Several renewable primary energy sources generate electricity via prior thermal generation. These technologies can, therefore, enjoy a double low-carbon benefit. First, the use of renewables bears obvious low-carbon credentials. Second, by operating in co-generation mode, these technologies enjoy the benefits of energy efficiency—another key low-carbon solution.

Biomass

Biomass co-generation is a prime example of how renewables and co-generation can be combined. Biomass co-generation refers to the use of biological material as feedstock for co-generation plants. The biomass resource can take a variety of forms and shapes. It can be in solid form such as agricultural residues, wood wastes from forestry and industry, residues from food and paper industries, green municipal solid waste (MSW), dedicated energy crops and reclaimed wood. Biomass can be in gas form including in the form of landfill gas, manure biogas and wastewater treatment biogas. Alternatively, it can also be fed indirectly to generating plants through gasification of solid biomass or production of liquid biofuel.

Figure 10 • The importance of biomass co-generation compared to overall co-generated electricity production

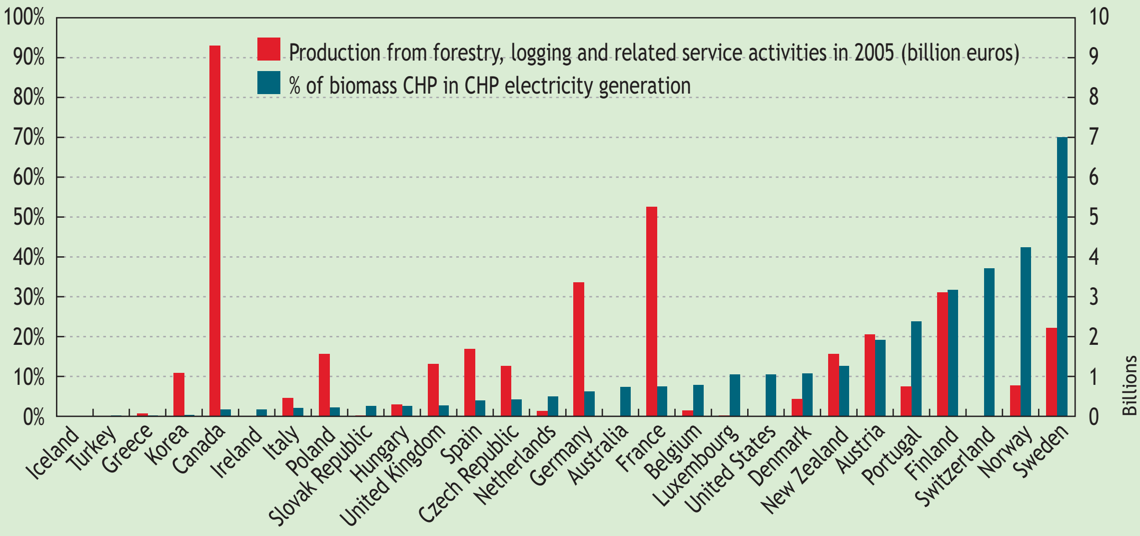


In some countries, biomass co-generation already represents a significant share of co-generated electricity — a trend that may reflect local circumstances (Figure 10). As biomass resources are abundant in countries that have a large forestry industry, it is expected that such countries should have the highest proportions of biomass in the fuel mix for co-generation. Finland and New Zealand, which are known to have large forest plantations, also have a high proportion of biomass co-generation (Figure 11). Other countries, such as Norway and Portugal also have good penetration rates of biomass in their co-generated electricity production despite relatively small forestry industries. For example, reclaimed wood from old buildings can also be a source of biomass. Canada and France, both of which have large forestry industries, show ample capacity for increased biomass co-generation.

The forestry and wood processing industries generate large amounts of waste biomass that could be given value as fuel in co-generation plants either in pure biomass-fuelled plants or in plants that use biomass co-fired with other combustible fuels. Two biomass co-generation projects under development use mainly forestry products and/or reclaimed wood as fuel (Box 3). The biomass fuel for these projects does not compete with the many applications that require virgin, prime biomass or biomass that might be destined for food production. On the other hand, in some countries, including

Sweden and Germany, there is an ongoing discussion about using co-generation as a means to "dilute" coal by mixing it with biomass in co-generation plants. As a side note, it is worth pointing out that boiler/steam turbine technology currently employed in most biomass-fuelled projects, produces much more steam than electricity. This supports the use of co-generation to increase the overall energy efficiency of such projects. However, in most regions, the demand for electricity is growing faster than the demand for heat. There is, thus, a market demand for new technologies that can use renewable biomass to produce a high ratio of electricity to thermal output at high efficiencies.

Figure 11 • The importance of the forestry industry compared to biomass co-generation penetration

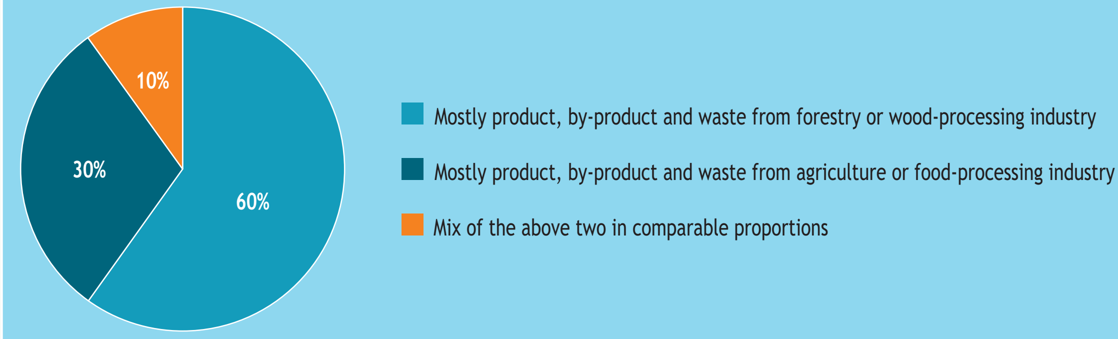


Note: No forestry industry data were available for Turkey, Ireland, Australia, the United States or Switzerland.
Source: IEA data and analysis, 2008; OECD data, 2005, reflecting IEA analysis.

Box 3 • Renewable, biomass-fuelled co-generation projects

Cofély/Sofiprotéol, France

Figure 12 • Source of biomass fuel for the 56 projects submitted under a French Ministry of Industry call for proposals



Source: Data from French Republic, 2008.

In 2008, the French Ministry of Industry shortlisted 22 out of 56 project proposals submitted following a call for proposal for projects to produce power from biomass using a variety of sources for the biomass fuel (French Republic, 2008) (Figure 12). The projects were rated based on several factors with energy efficiency carrying about 25% of the weighting. A project presented by Cofély, a major co-generation project developer and Sofiprotéol, a major agro-industrial company, was one of those selected (Cofély Centre-Ouest, 2010). The biomass co-generation plant to be built in Grand-Couronne (northern France) will supply 400 000 tonnes of steam per year for the production of vegetable oil, animal meal and biodiesel from rapeseed. With a capacity of 9 MW, the plant will sell electricity to *Electricité de France* (EDF), the public utility company. The project proponents calculate the project will allow a 72 000 tonnes CO_2 emissions reduction per year. In April 2010, the French Minister of Food, Agriculture and Fisheries laid the foundation stone for the plant, which is expected to be commissioned in May 2011.

RWE/Tullis Russell, Scotland

Construction on a 45 MW biomass co-generation plant started in November 2010 in Markinch, Scotland. The biomass fuel will be made up primarily of reclaimed wood normally directed to landfills. Besides electricity, the co-generation plant will provide the paper mill with the steam it needs for paper drying. Some electricity will also be exported to the national grid. The project is a partnership between RWE npower renewables and Tullis Russell, a paper manufacturer present in the community for more than 200 years (RWE/Tullis Russell, 2010). The promoter calculates that a reduction in CO_2 in excess of 250 000 tonnes per year will be achieved. The Scottish Government is supporting the GBP 200 million project with a GBP 8.1 million grant (The Scottish Government, 2008) and the plant is scheduled to start production in late 2012.

These projects (Box 3) show the importance of advance heat planning and local partnering to realise the full potential of co-generation. At the onset of the project, planning how the heat from power production will be used avoids the cost disincentive of future expensive retrofitting to convert a power-only generation plant into a co-generation plant. Major project developers partnering with local manufacturing companies promote low-carbon solutions that are environmentally beneficial. In addition, they increase local sourcing of fuel, thereby enhancing energy security, and increase/maintain local economic activity through job creation and other co-benefits.

Geothermal

Geothermal power plants use heat energy from below the Earth's surface to produce electricity. The heat energy is in the form of steam that results from the decompression of geothermal fluid as it travels from reservoirs (located at several hundred to a few thousand meters underground) to the surface of the Earth. There are three types of geothermal power plants, each one differing because of the composition of the geothermal resource and the temperature level of the resource: steam only, steam in combination with water and water only. High temperature reservoirs consisting of steam only can be used directly to drive steam turbines in dry steam power plants. High temperature geothermal resources consisting of both water and steam are first allowed to "flash"[2] so that the mixture is converted to steam: the steam is then used to drive a turbine. In the third type of plant (binary plants), geothermal resources are fed to a heat exchanger to produce steam indirectly. These typically operate with lower temperature geothermal resources in water form, with temperatures varying from as low as 70°C to 180°C.

The hot water remaining from electricity generation – independent of the type of geothermal power plant – can be used in cascade methods for district heating and other direct heat use applications. In high temperature geothermal resources, heat may be regarded as a by-product of geothermal power production in terms of either waste heat released by the generating units or excess heat from the geothermal source. Power generation from lower temperature sources in binary plants usually strive

2. When a liquid is under high pressure and at high temperature, releasing the pressure suddenly can cause the liquid to spontaneously turn into its vapour form. The liquid is said to "flash".

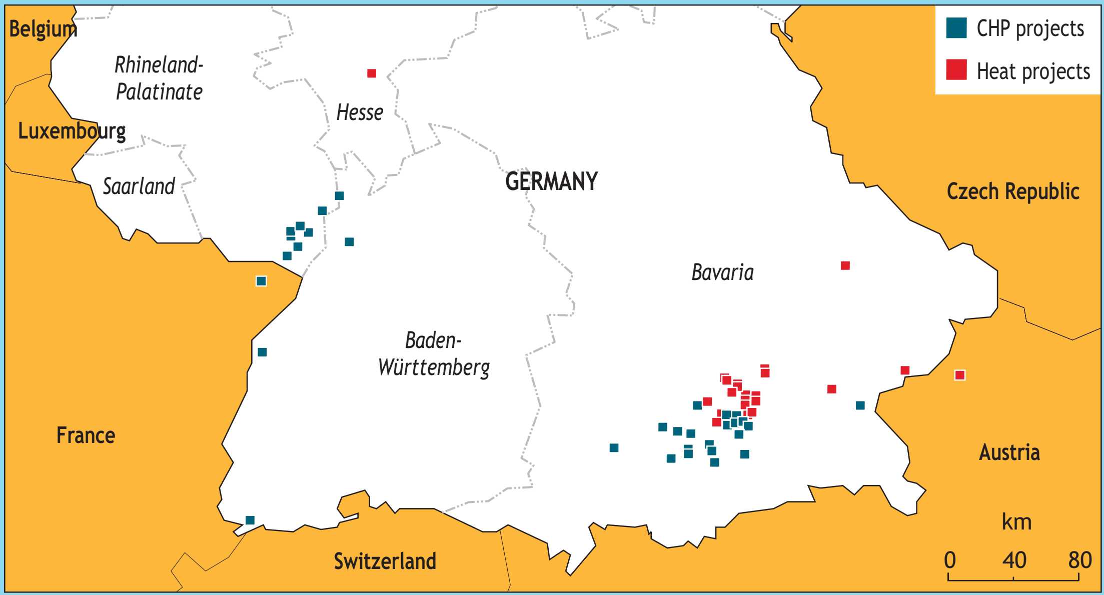
for economic viability by seeking an additional revenue stream from the sale of heat. Today, examples of geothermal co-generation where heat is delivered to district heating grids can be found in Iceland, Italy, Germany and Turkey. Strong policy support for renewable energy – particularly for renewable electricity – in the European Union has resulted in recent increased efforts to use geothermal resources for co-generation plants. Co-generation is intrinsic to two new geothermal projects now under development in Croatia and Germany (Box 4).

Box 4 • Geothermal co-generation in Croatia and Germany

In Croatia, the development of a first co-generation geothermal plant is expected to be completed in 2012, using the geothermal resources of the Pannonian Basin. The plant will use the 175°C geothermal resource for the simultaneous production of electricity (4.71 MW) and heat (10 MW). After power production, the geothermal resource remaining at 69°C will be used for heating purposes, cooling it down to 36°C. The geothermal power plant will operate 8 700 hours per year. It is expected to be in production for at least 30 years and up to 50 years in a positive scenario. In addition to construction of a geothermal power plant, a new business and tourist facility is planned for the future, with outdoor and indoor pools, greenhouses and fish farms. Investors are interested in pursuing these additional activities that benefit from the available low-cost geothermal heat. The expectation is that 265 people will be employed within the project, 15 of them to be allocated to the power plant. The geothermal power production will earn a purchase price of EUR 0.18 kWh (2010), which has been guaranteed by the local public utility for the period of 12 years.

Germany does not have access to high heat-content resources at shallow depth, but can make use of medium temperature hydrothermal resources in the aquifers of the North German Sedimentary Basin, the Molasse Basin and the Upper Rhine Graben. These hydrothermal reservoirs contain water with temperatures of 50°C and up to 130°C, allowing for power production via organic Rankine cycle (ORC) and/or Kalina cycle techniques. At the start of 2010, three geothermal co-generation plants were in operation in Germany (Schmellschmidt *et al.*, 2010).

Figure 13 • Geothermal co-generation plants and heat only plants under development in the Upper Rhine Graben region (2010)



This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

Source: BE Geothermal, www.begeothermal.com.

Strong economic framework conditions exist for geothermal development; in Germany the Renewable Energy Sources Act guarantees system operators fixed payments for geothermal electricity fed into the grid. As of January 2009, the feed-in tariffs for geothermal plants with a plant capacity below 10 MW is EUR 0.16 kWh (above 10MW: EUR 0.10 kWh). On top of this basic tariff, a bonus of EUR 0.03 kWh is available specifically for geothermal co-generation. If the plant starts running before 2015, an additional bonus of EUR 0.04kWh is available. When using enhanced geothermal systems (EGS) technology, an additional EUR 0.04 kWh can be obtained. In a best case scenario, a geothermal co-generation plant with a capacity below 10 MW, starting operation before 2015 and using EGS technology can receive a EUR 0.27 kWh feed-in tariff.

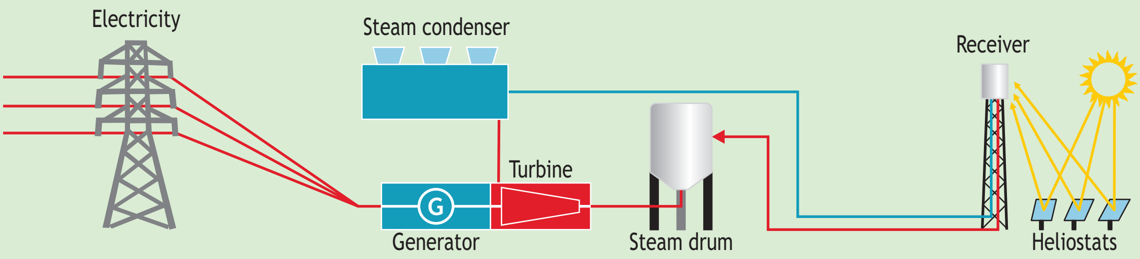
The prevailing economic and political conditions have spurred geothermal development and geothermal co-generation in Germany. At the end of 2010, about ten geothermal co-generation plants were under construction in the Rhine Graben and Molasse Basin region while applications for exploration permits has been submitted for a further 150 sites (Schellschmidt, *et al.*, 2010).

The incentives framework for geothermal energy in Germany (Box 4) and the corresponding positive impact it has had on spurring new projects show that aggressive feed-in tariffs for renewables and co-generation can stimulate new projects.

Concentrating solar power

Concentrating solar power (CSP) converts solar energy into thermal energy which is then converted into electricity. The second process is achieved most often through a steam turbine as in most conventional power plants that rely on the steam cycle to drive an electric generator (Figure 14).

Figure 14 • Tower concentrating solar power (CSP) technology



Source: Adapted from US Department of Energy, National Renewable Energy Laboratory.

As with any technology that generates power through prior heat generation, CSP has scope for the application of co-generation. Isolated locations receiving large amounts of direct sunshine such as deserts are particularly suitable for solar CSP plants, but located far from energy demand and must deal with transmission issues. Other regions such as the Middle East and North Africa (MENA), south-western United States and the Mediterranean, which have the best potential for solar CSP, are relatively close to inhabited and/or industrial areas. Some large metropolitan areas in diverse parts of the world including Athens, Cairo, Houston, Istanbul, Jaipur, Johannesburg, Lima, Riyadh and Sydney are likely to benefit from CSP by 2020 (IEA, 2010(i)). With proper planning, heat derived from CSP can be used gainfully to dramatically increase the overall efficiency of a CSP system.

While CSP has been reliably operating for at least 15 years in some countries such as the United States, it is still an emerging technology when considering the amount of electricity currently generated. Various projections (IEA, 2010(i)) show a substantial increase in power generation from CSP in the coming years. It is important to take advantage of new project developments to benefit from the most energy efficient options. CSP operating in co-generation mode is one such option. One application in which heat from CSP plants could be used is desalination, especially at a time when many regions that are suitable for CSP due their large levels of solar irradiation, face severe fresh water deficits. Box 5 explains how heat from CSP plants could assist in providing fresh water in regions deprived of clean supplies. Additional opportunities may exist in the industrial sector. For example, in South Africa, Anglo American — South Africa's largest mining company — is considering building a 100 MW CSP facility in the Northern Cape region of the country to generate 60 MW capacity for its Sishen iron ore mine, (*Financial Times*, 2010). The plant could be made even more energy efficient by using some of the heat generated on site to meet either heating needs or for cooling purposes (Box 2).

Box 5 • Concentrated solar power (CSP) and desalination

Many arid regions of the world are becoming more dependent on technology, including desalination processes, to help meet growing demand for fresh water. Two main technologies account for most of desalinated water production:

Distillation involves boiling seawater and collecting the water vapour which, after condensation, yields fresh water. The technical names of the methods used are multi-stage flash distillation (MSF) and multi-effect distillation (MED).

Filtration is conducted by pumping seawater through a porous membrane that allows the passage of smaller water molecules but blocks larger salt molecules, thus producing fresh water on the other side of the membrane. This process is known as reverse osmosis (RO).

Both are energy-intensive technologies though filtration tends to be more energy-efficient. Distillation requires heat energy, normally in the form of low temperature steam in the range of 70°C to 110°C, for evaporation. Filtration requires electrical energy for pumping.

In 2006, a Jordanian/German consortium performed a technical and economical feasibility study for the production of 10 MW of power, 10 000 tonne (t) per day of desalinated water and 40 MW cooling capacity for the Ayla Oasis Hotel Resort in Aqaba, Jordan (Trieb *et al.*, 2009). The team investigated both a conventional solution using gas as the only energy source and an integrated solution using gas and solar energy sources (CSP was the chosen solar technology). The study showed that the integrated process, using CSP and co-generation, required 34% less fossil fuel (gas) than the conventional solution. Although project promoters subsequently decided not to go ahead with the project, the study showed that the integrated option could be realised with a good internal rate of return — even without relying on subsidies.

Table 1 • Options for power, cooling and desalination at the Ayla Oasis Hotel Resort project in Aqaba, Jordan

	Conventional solution	Conventional solution + co-generation	Integrated solution (co-generation + sun)
Energy input (MW)			
Gas	85	70	56
Sun	0	0	14
Desalination technology used			
Electricity-driven reverse osmosis	■	□	□
Heat-driven distillation	□	■	■
Cooling technology used			
Electricity-driven compression chilling	■	■	■
Heat-driven absorption chilling	□	■	■
Utilities output	Electricity: 10MW, cooling: 40MW and water: 400 t/h		
Gas savings compared to conventional solution	0%	18%	34%

Source: Data from Trieb et al.*, 2009.*

Using the heat may have the added benefit of reducing the cooling water requirements of a CSP system. By finding a use for excess heat from CSP plants, co-generation can lower the amount of water required to cool the system. This can make the CSP plant project more viable. Any plant that relies on heat generation to produce steam and generate power must also have a means to remove excess heat from the system once the steam has left the turbine (this is performed by the steam condenser component in Figure 14). This is usually done by circulating cold water to cool the system. CSP systems, which are likely to be sited in water-deprived regions, may face an additional hurdle if not enough water is available to cool the system. Recent growth in the number of new CSP projects, especially in water-deprived regions in the south-western parts of the United States, prompted the US Congress to specifically mandate the US Department of Energy to study and report on ways to reduce water consumption by CSP plants (NREL, 2008).

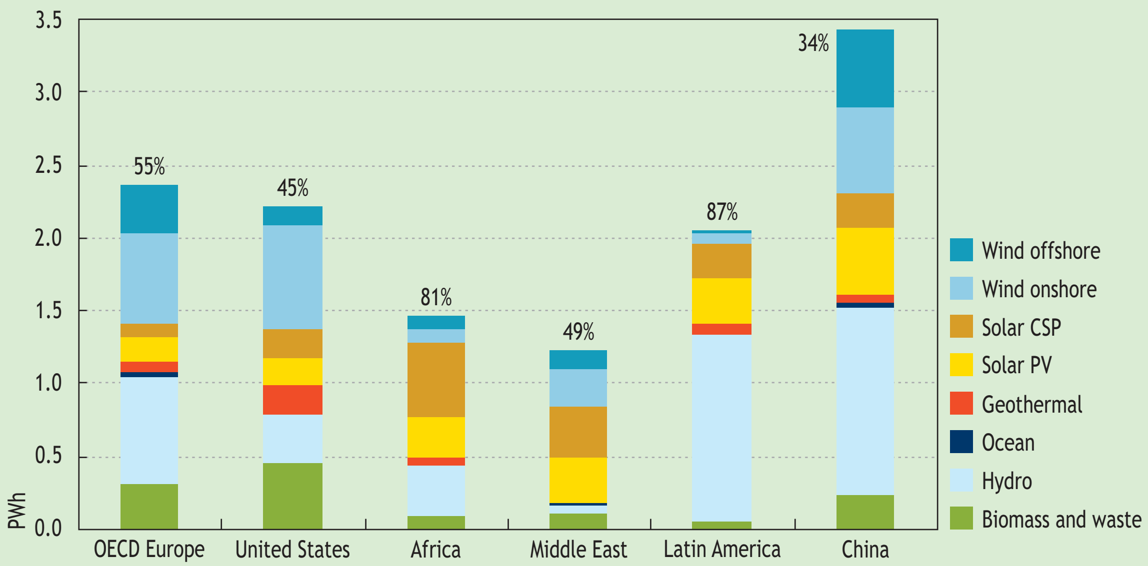
Co-generation and Variable Renewable Electricity Production

In an electricity system, a dynamic balance must constantly be achieved between demand and supply. Several renewable technologies are inherently variable: the wind does not blow continuously, the sun does not shine all day and waves do not always crash. This creates variability in their supply to power systems. Because some renewable technologies introduce an additional element of variability in the system, they can be perceived as a less attractive option within a range of energy technology options. But variability is not a new challenge in power system balancing. Electricity demand also fluctuates, whether daily or seasonally. Wind power, wave and tidal power, run-of-the-river hydropower and solar power can all be considered as part of variable renewable electricity (var-RE) technologies. Under the right conditions, co-generation systems coupled with renewable electricity systems can assist in balancing, thereby increasing the viability of var-RE projects.

Renewable electricity generation forecast

Planned integration of var-RE into the electricity generation mix can make var-RE a much greater contributor towards electricity generation compared to the current position. Over the last decade, IEA countries have seen exponential growth in the share of non-hydro renewables in electricity production — largely driven by wind (Figure 3). Despite growth in the sector, the share of non-hydro renewables in electricity generation was still below 5% in 2009. Much higher integration of renewables, including var-RE, will be needed to decarbonise the energy system according to IEA forecasts (IEA, 2010(h)) (Figure 15).

Figure 15 • Renewable electricity generation in the BLUE Map Scenario for key countries and regions in 2050



Source: IEA, 2010(h).

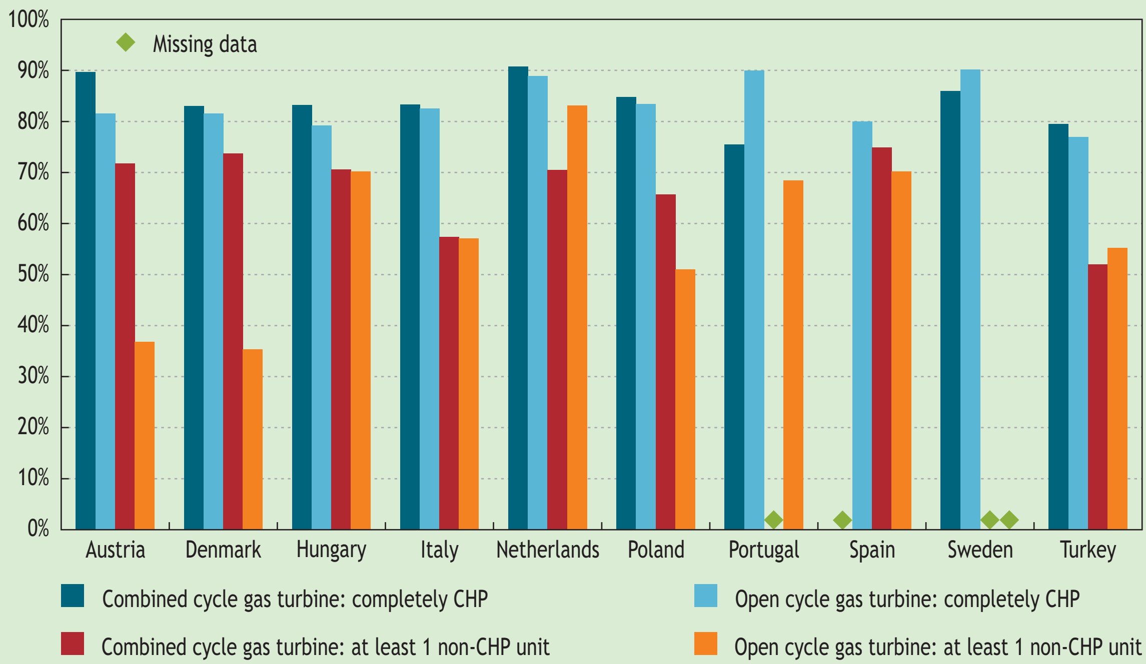
Balancing variable renewable electricity production through thermal storage

Various strategies can be considered to minimise the potentially disrupting impact of var-RE on the balance between demand and supply of electricity at any given time. These include combining the outputs of a large number of var-RE plants over a large geographical area, aggregating different var-RE technologies that have an inverse correlation or better forecasting to allow firm electricity-generating technologies to be scheduled more appropriately (IEA, 2008(c)). Having spare generating capacity on stand-by is a common strategy to address real-time electricity demand/supply mismatches, regardless of cause. Such so-called backup technologies, by definition must be capable of changing their level of electricity production at short notice to compensate for temporary supply deficits. Gas-fired power plants are some of the fastest to ramp up or down making them good candidates for backing up var-RE. Gas-fired plants are already among the most common types of plant used to meet peak load demands.

In its submission to the UK National Grid on the future operation of the electricity transmission network, EDF Energy (a major UK electricity producer) states, “It is likely that the growth of wind capacity will have to be matched to a large extent by back up fossil plant... It is also possible that in response to market signals due to the intermittency of wind power, investors are likely to favour fast response technologies as backup, such as open-cycle gas generation which have high carbon emissions” (EDF Energy, 2009).

Gas plants have relatively high carbon emissions per unit of useful energy generated—carbon intensity- if a large portion of the input energy is wasted. It would be counter-productive if renewable energy technologies introduced in part to mitigate carbon dioxide emissions end up losing some of their green credentials because of required gas-fired backup systems. The carbon intensity of gas-fired plants can be greatly reduced if, besides the electricity from gas-fired plants, the resultant excess heat generated is also put to good use. For the same level of carbon emissions, more useful energy is generated. The process of assigning value to heat from power plants increases the overall efficiency. Figure 16 shows the overall efficiency, *i.e.* combining useful electricity and heat produced, of gas turbine power plants with a co-generation component, in IEA member countries for which data are available. Across countries, the least efficient purely CHP plant is more efficient than the most efficient plant with at least one non-CHP unit.[3]

Figure 16 • Impact of co-generation on the overall (electricity and heat) efficiency of gas turbine power plants in IEA countries for which data is available



3. A power plant may have several generating units. A purely CHP plant is one at which all units are co-generation units. “At least one non-CHP unit”, as the name suggests, does not specify the number of CHP units. For example, it could be 1 non-CHP unit and 29 CHP units (close to a completely CHP situation) or 29 non-CHP units and 1 CHP unit (close to a non-CHP situation).

There are slight discrepancies in the way different countries interpret and report their data so the most accurate means of comparison is to look at the data on a country-by-country basis. Each one applies the same methodology giving a consistent result. In this way the findings show that within any country, purely CHP plants are always more efficient. This confirms that gas-fired turbines working in co-generation mode are more efficient. While the data relate only to turbines, the conclusions would also be the same for engines.

As it is likely that backup for var-RE will be largely in the form of gas-fired plants, it makes sense to use the most efficient types of gas-fired plants: co-generation gas-fired plants. Looking at the future prospects for natural gas in Europe the IEA *World Energy Outlook 2009* states, "Gas-fired capacity can also support indirectly Europe's drive to increase the share of electricity generated from renewable energy sources... Gas turbines are able to respond quickly to the need for additional generation and their relatively low capital cost makes them a preferred choice to provide back up capacity. This means that an increasing share of electricity generated from renewable sources can be associated with continued growth in gas-fired capacity." The scale of planned var-RE integration and the likelihood that backup will be gas-fired makes it even more important to choose the most efficient type of gas-fired generation technology. Failure to do so will cancel some of the carbon mitigation benefits of introducing renewable energy generation. Overall, the argument holds if the heat source being replaced is a high-carbon intensity source of heat. Thus, by running gas-fired backup plants in co-generation mode it is possible to assist in smoothing out the variability due to var-RE while at the same time keeping carbon emissions at a low level — hence, the low-carbon solution.

A co-generation gas-fired plant used for backing up var-RE will be subject to variations in its heat supply that would likely be unacceptable for heat end-users. Fluctuations in heat supply can be smoothed out by the use of heat storage techniques, eventually supported by highly efficient boilers. Münster and Lund (2007) state that "storing heat is simple but storing electricity is still difficult and expensive". In fact, the ease of storing heat depends greatly on the form in which heat is stored and the length of time for which it is stored. It is relatively straightforward and simple to store low-grade heat (up to 100°C) for time intervals of up to 48 hours. Storing higher temperature heat and/or storing heat for longer periods (including seasonal storage), is technically possible but, with current technology, would be much more complex. Nevertheless, many applications can benefit from low grade heat (below 100°C): district heating is an obvious example, but several industrial applications can also benefit: 30% of total industrial heat demand in 32 European countries is for low grade heat below 100°C (Figure 9). Coupling co-generation plants with heat accumulators can be a viable option to provide backup for renewables in an energy-efficient, low-carbon way. The option would involve operating backup plants (presumably gas-fired plants as explained above) and storing excess heat energy when power generation from var-RE is low. When var-RE power generation is high, gas-fired plants would be turned down and heat would be supplied from heat storage. In practice, to add flexibility, gas-fired and/or electricity boilers would be used for heat supply only. Boilers for heat supply tend to be highly efficient.

Thermal stores at co-generation plants are already in use in a number of places, albeit not necessarily for balancing var-RE. Some co-generation systems are designed to operate at times of peak electricity demand and, thus, high electricity price to maximise the revenue from the electricity generated. The use of thermal stores is warranted to store the heat produced so that it can be used when it is needed. The operational co-generation district heating systems at Woking and Barkantine in the United Kingdom are examples of such a set-up (Kelly and Pollitt, 2009). This application of co-generation shows that it can be used to match a fluctuating electricity demand, which is the case if co-generation is to be used as backup for renewables. Supply of cogenerated electricity is positively correlated with spot electricity price, which is presumably negatively correlated with supply of var-RE — *i.e.* availability of var-RE increases supply, driving down price. This means supply of cogenerated electricity will be negatively correlated with supply of renewable electricity — *i.e.* the situation that arises when backup is involved.

The Hvide Sande[4] co-generation plant in Denmark is another example of price-determined, thus variable, electricity production from a co-generation plant. Figure 17 shows a screenshot of operating data from the plant and also shows the corresponding electricity spot price, updated every two minutes.

Box 6 • Investigating the potential for integrating var-RE through co-generation and heat storage

To investigate this potential an EU-funded project, Project DESIRE[5] (European Union, 2008) was conducted from June 2005 to May 2007. The project aim was to disseminate practices which will integrate fluctuating renewable electricity supplies such as wind power into electricity systems using combined heat and power.

The project focused specifically on co-generation systems where production is modulated by electricity supply, itself determined by the day-to-day electricity price. Electricity was sold both on one-hour and one-day ahead spot markets and 15-minutes regulating markets. Trading on markets with such short intervals between bidding closure and actual delivery, shows how fast co-generated electricity production can react to balance var-RE. The electricity was sold on power markets in Denmark, Germany and the United Kingdom.

The research showed that when wind turbines are producing a large amount of electricity, co-generation plants reduce their production of electricity because spot prices are low. At these times, co-generation plants cover heat demand from thermal stores. The DESIRE project concluded that there is good potential for making co-generation plants and wind turbines operate together through the spot market. Unlike co-generated electricity, wind-generated electricity may not be traded on the spot market, but it still influences trading through its impact on the amount of electricity the spot market needs to supply.

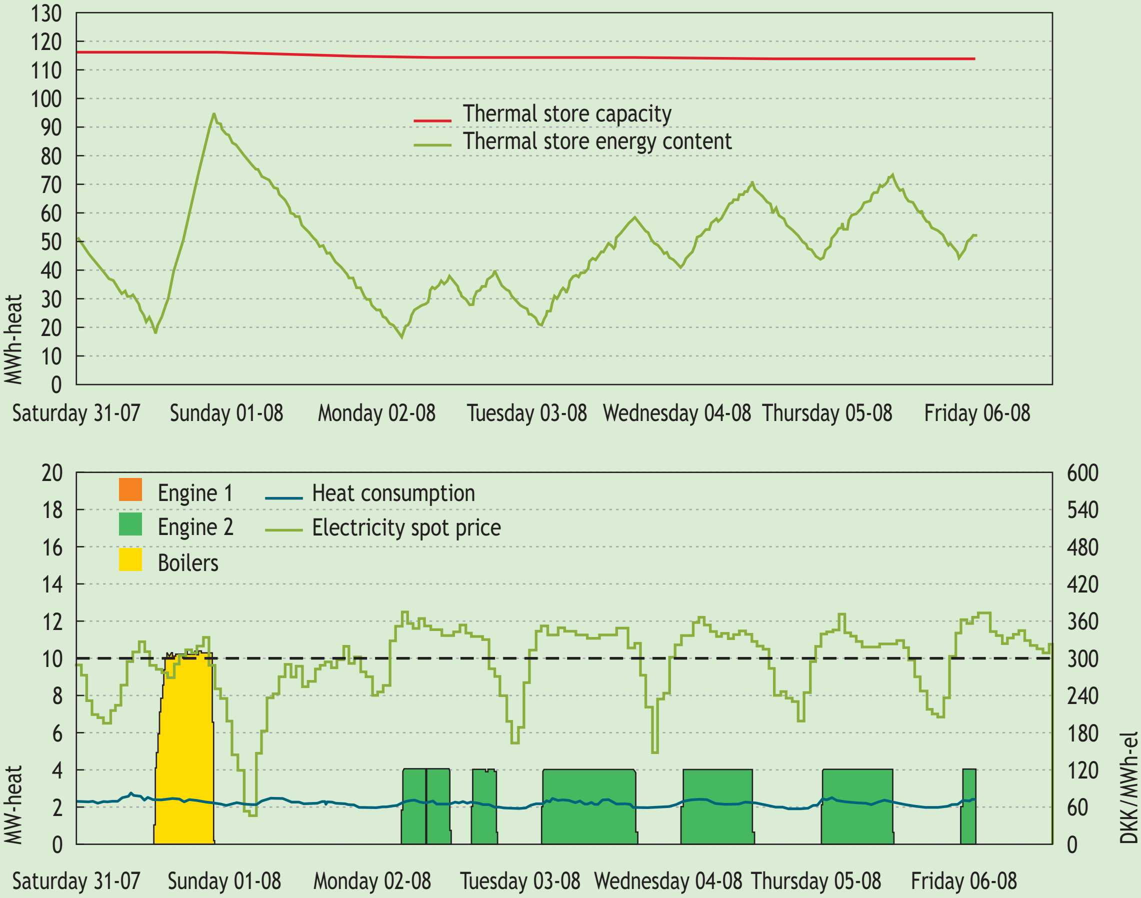
For obvious reasons, Hvide Sande CHP does not disclose its production strategy or specific operational events (*e.g.* unit taken offline for maintenance), but the online production data give useful hints. The gas engine operating in co-generation mode is run when the electricity spot price is highest, roughly above DKK 300/MWh-el (broken bold line). When the gas engine is operated, the heat produced alongside electricity is stored and the thermal-store energy content is seen to increase accordingly in the upper graph in Figure 17. When the engine is not running, heat is supplied from storage and the thermal store energy content is seen to decrease. If it is not economical to run the engine to produce electricity and heat, highly efficient boilers are used to produce heat only to replenish the thermal store energy content. Denmark, where the Hvide Sande plant is located, has the highest penetration of both co-generation and var-RE (mainly wind) in the world. This makes it a good case to study the interaction of co-generation and var-RE.

The above example shows that it is technically possible for a co-generation plant to respond to changes in variable electricity supply while meeting a constant heat demand through the use of thermal storage and/or auxiliary boilers. This has the benefit of maximising the energy efficiency associated with the use of a fossil fuel (gas) in a situation — renewables back up — where that fuel could well be hardly replaceable. Under current financial frameworks, it seems unlikely that co-generation operators would be motivated to invest the required up-front capital expenditure (*e.g.* thermal stores, auxiliary boilers, etc.) to participate in the unpredictable business of balancing variable renewable electricity generation. Thus, without adequate policy incentives specifically addressing the financial uncertainty associated with high up-front capital investment and unpredictable future cash flow, it seems unlikely that such schemes will be implemented despite their potential low-carbon benefits.

4. The Hvide Sande CHP plant has the following characteristics: two natural gas-fired engines with electricity production capacity of 3.77 MW and heat production capacity of 4.9 MW. Further, it has two boilers with heat production capacities of 4 MW (natural gas) and 10 MW (natural gas/oil). Heat is stored in a 2 000 m^3 tank with a holding capacity of 130 MWh heat.

5. DESIRE stands for "Dissemination strategy on electricity balancing for large scale integration of renewable energy".

Figure 17 • The impact of electricity spot price on the operation of the Hvide Sande co-generation plant (Hvide Sande CHP history: 31/07/2010-06/08/2010)



Source: www.emd.dk/desire/hvidesande/hvidesandeHistory.php.

Additional applications of co-generation for variable renewable electricity back up

The fact that co-generation allows two different forms of energy — electricity and heat — to be bridged, should allow for other innovative solutions to be found. For example, heat generation from a co-generation plant can affect its level of electricity generation especially when the heat supplied is high pressure, high temperature heat such as for some industrial applications (Figure 9). More high temperature heat production can equate to less electricity generated and vice versa. Some industrial co-generation plant developers see this as a trade-off; in some markets they have less incentive to produce heat since electricity is a more valuable form of energy. Financially, it can be more advantageous for them to maximise electricity production for sale and purchase heat (through buying fuel for boilers) rather than to reduce electricity production in favour of heat production. In other jurisdictions, some industrial co-generation operators that have the capacity and might want to export more electricity to improve the economics of their co-generation plant are limited by utilities in the amount of electricity they are allowed to export; circumstances vary.

However, the fact that heat and electricity generation are coupled means there is a possibility of adjusting electricity production from co-generation to match electricity production from var-RE by producing more or less high temperature heat, *i.e.* adjusting the power to heat ratio based on electricity demand. The overall supply of high temperature heat could be kept stable by using heat storage and/or making use of (high-efficiency) auxiliary boilers (most industrial co-generation systems already feature auxiliary boilers). Prayon, a Belgian chemical company, operates its co-generation system in a flexible way, based not on electricity demand but on the price of both utilities (electricity and heat) (Box 7).

Box 7 • Flexible operation of a co-generation system at a chemical plant

Prayon has been producing sulphuric acid since 1888 at its production site in Engis (near Liège, Belgium). It uses sulphuric acid to produce phosphoric acid on-site to manufacture fertilisers. To meet its growing acid needs, Prayon invested EUR 50 million in 2008 to build a new 1 000 t/d sulphuric acid plant. As sulphuric acid production is exothermic, large amounts of heat are generated during the production process.

Prayon's new plant has a heat recovery module that takes advantage of the excess heat and captures it to produce steam and electricity in a co-generation plant. The new co-generation plant covers 70% of the electricity consumption and 35% of the heat requirements of the whole site. Besides the savings linked to on-site electricity production (as opposed to sourcing through the grid), direct savings result through substantial reductions in natural gas purchases and suppression of fuel oil purchases for on-site steam production.

In recognition of its performance, the Prayon plant was awarded a EUR 1.9 million energy and environment grant from the Walloon region of Belgium. It is interesting to note that the company reports the new co-generation plant enables the production of steam over electricity and vice versa depending on plant requirements and the respective cost of each utility (Prayon, 2010). This shows that given the right incentive — in this case the price of each utility — a chemical plant can adjust its electricity production. Similarly, if the incentives exist, industrial manufacturers, that have the advantage of a fairly constant heat demand daily and seasonally, could assist in balancing var-RE.

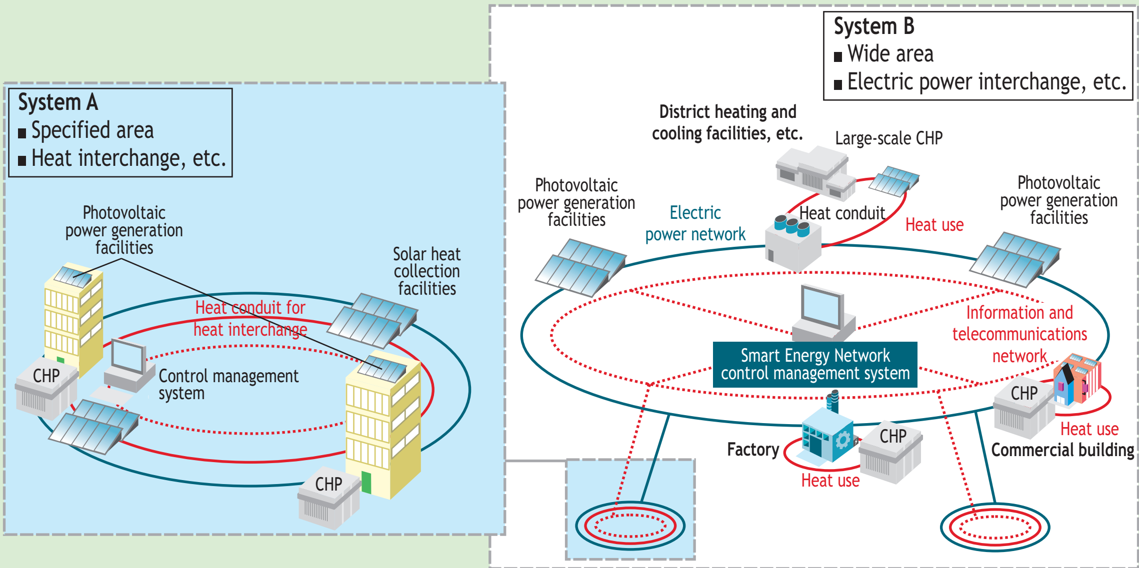
Another example relates to combined water and power (CWP) plants. The IEA predicts that desalination capacity in the Middle East and North Africa will grow from 21 million cubic metres (mcm) of water per day in 2007 to 110 mcm per day by 2030 (IEA, 2009(f)). Currently, the main desalination technology (distillation) is heavily energy-intensive due to its heat requirements; using heat from power generation can help lower primary energy sources requirements as opposed to separate power and heat production. Some of the regions with needs for desalination also have plans for increased electricity generation from solar sources, including solar PV, which produces very little heat as a by-product. Fossil-fuelled plants used to back up these solar-powered plants could, when under operation, also be used to support the production of desalinated water. During the night, when fossil-fuelled plants are operated to make-up for lack of electricity production from solar PV plants, the heat by-product could be fed to desalination plants to produce water. Desalinated water is even easier to store than heat and excess desalinated water produced during the night can be stored to meet daytime needs.

These scenarios are not based on any technical or economic assessment, but do illustrate the point: by combining electricity generation with heat generation, co-generation increases flexibility in the energy system. When a system is larger there is a higher likelihood that a surplus in one part of the system can be balanced by a deficit elsewhere. The reasoning is similar to that of interconnecting various national grids to achieve greater flexibility. The fundamental characteristic that makes co-generation a viable candidate for backing up var-RE, is the link it provides between electricity and heat—two forms of energy that when usefully employed greatly improve energy efficiency.

Tokyo Gas and Osaka Gas are testing this flexibility within the Smart Energy Network demonstration project, launched in May 2010. The Japanese Ministry of Economy, Trade and Industry (METI) selected the project as one of its Dispersed Energy Compound Optimisation Demonstration Projects (Tokyo Gas/Osaka Gas, 2010). The project aims to demonstrate the potential for optimisation of heat and electricity production and consumption, beginning on a small scale within a localised community, System A. It will then seek to optimise electricity exchanges on a wider scale for a cluster of Systems A called System B, (Figure 18). In System A, both heat and electricity produced by co-generation, solar heat collection and photovoltaic power generation will be interchanged among several buildings.

In System B, only electricity will be interchanged. The partner companies expect the project will promote "the introduction of photovoltaic power generation by supplementing photovoltaic power – whose output fluctuates depending on the weather – with co-generation" (Tokyo Gas/Osaka Gas, 2010).

Figure 18 • Tokyo Gas and Osaka Gas Smart Energy Network demonstration project



Source: Tokyo Gas and Osaka Gas.

Conclusions

This report considers the potential synergies between co-generation and renewables. Each has strong carbon mitigation credentials. Using the two together can achieve powerful low-carbon energy solutions that complement each other. However, strong policy support is needed if they are to reach their full low-carbon energy potential.

As the IEA publication, *ETP 2010* (IEA, 2010(h)) shows, energy efficiency is one of the most powerful tools that can be used to meet energy-related challenges. It is available now if there is sufficient support from policy makers to make it a reality. In traditional power generation nearly two thirds of input energy is lost in the air. The energy efficient compact fluorescent lamp (CFL) is readily available now, but it took more than a century to make the shift from the incandescent lamp to CFLs. If we wait for another century for co-generation to be the next CFL, it will be too late. Adequate policy support is required now.

The previous publication in the IEA CHP Collaborative series, *Co-generation and District Energy: Sustainable Energy Technologies for Today and Tomorrow*[6] (IEA, 2009(e)) identifies several effective policy tools policymakers can apply to support co-generation. It identifies three critical factors for success:

- A co-generation strategy at the national level, covering technology development, incentives where needed, grid interconnection, and outreach/awareness, among other initiatives, with a government department/agency to implement the strategy;
- A strategic approach to infrastructure planning to match supply and demand;
- Targeted implementation levels to meet different needs at the national, state/provincial and local levels.

Renewables is another powerful ally that is waiting in the background. The current energy supply is structured in such a way that it is rapidly using up resources that cannot be renewed. The change from a primarily fossil-based energy supply system to a primarily renewables-based system will take decades. During the transition, both renewables and fossil fuels will co-exist.

Well-known barriers to deployment of renewable energy consist of economic barriers such as high up-front capital costs, unknown savings over time due to fluctuating fossil fuel prices, and competition from other well-established technologies that enjoy economies of scale. Other barriers are technical development issues (such as improved storage technology) and market and institutional barriers (such as permitting procedures). Maintaining a policy framework for renewables — for as long as necessary to bridge the competitiveness gap between renewables and traditional alternative energy technologies — will be crucial. The IEA publication *Deploying Renewables: Principles for Effective Policies*[7] (IEA, 2008(b)), provides an analysis of policy tools to support renewables.

Co-generation technology has the advantage of being able to contribute to renewable power deployment, and to renewable heat. Unlike renewables for transportation and electricity sectors, in which a large number of policies exist to promote the use of biofuels and renewables-based electricity, renewables for heat currently receive little policy attention. A greater level of policy attention for renewable heat should focus on looking for ways to better allocate and distribute the additional costs of renewable heating in order to make it independent of government budgets and/or align it with the "polluter-pays" principle. This might be more complicated in the heat market though, due to the more heterogeneous delivery of heat and the heterogeneity of fuels used for heat production. An advantage of renewable heat produced by co-generation technologies is that the scale is sufficiently big to make it economically viable to measure the heat produced. This allows for the introduction of an incentive for the production of renewable heat, such as in a renewable energy feed-in tariff scheme, based on the assessment of generated heat output.

6. Available at: www.iea.org/files/CHPbrochure09.pdf

7. Available at: www.iea.org/textbase/nppdf/free/2008/DeployingRenewables2008.pdf.

Co-generation can reduce the carbon footprint of some technologies that will invariably be needed to balance the fluctuations in electricity production due to the variable nature of some renewable energy sources. Since co-generation offers well-established energy efficiency and carbon mitigation credentials, it should be a preferred solution. However, varying electricity production might change the economics of co-generation plant investments. Higher upfront investments might be required (*e.g.* need for thermal stores, auxiliary boilers, etc.), operating costs can increase (*e.g.* maintenance costs related to transient mode of operation) and revenue stream can be impacted (*e.g.* capacity factor). Also, an additional element of uncertainty in revenue generated is introduced.

Since the technical means are available to realise the potential for using co-generation as backup for var-RE in a manner that mitigates carbon emissions, sufficient incentives at the policy level could well be justified, that would enable co-generation to support the development of renewable energy systems. In particular, such incentives should address the challenges presented by high upfront investments and non-viable revenue streams.

This report has demonstrated that renewables and co-generation have the potential to work side-by-side to achieve a common low-carbon future. It has focused on three topics where both co-generation and renewables can play a significant role:

- the supply of heat which is often neglected in the energy debate;
- renewable-fuelled power generation technologies that can operate in co-generation mode; and
- the potential for co-generation to provide low-carbon back up for variable renewable electricity production.

The key message from this analysis reinforces the notion of both co-generation and renewables being low-carbon energy solutions.

Abbreviations and Acronyms

CCGT	combined-cycle gas turbine
CCS	carbon capture and storage
CFL	compact fluorescent lamp
CHP	combined heat and power (synonymous with co-generation)
CO_2	carbon dioxide
CSP	concentrating solar power
DESIRE	Dissemination strategy on Electricity balancing for large-Scale Integration of Renewable Energy
DKK	Danish krone
DLR	German Aerospace Centre
ETP	*Energy Technology Perspectives* (IEA publication)
EU	European Union
IEA	International Energy Agency
kWh	kilowatt hour
mcm	million cubic metres
MED	multi-effect distillation
MENA	Middle-East and North Africa
MSF	multi-stage flash distillation
MSW	municipal solid waste
MW	Megawatt
OECD	Organisation for Economic Cooperation and Development
OGCT	open-cycle gas turbine
PJ	petajoule
PV	photovoltaic
RD&D	research, development and deployment
RE	renewable energy
RO	reverse osmosis
TWh	terawatt hour
var-RE	variable renewable electricity
WEO	*World Energy Outlook* (IEA publication)

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Co-generation and Renewables

Solutions for a low-carbon energy future

Secure, reliable, affordable and clean energy supplies are fundamental to economic and social stability and development. Energy and environmental decision-makers are faced with major challenges that require action now in order to ensure a more sustainable future. More efficient use of, and cleaner primary energy sources can help to achieve this goal. Co-generation – also known as combined heat and power (CHP) – represents a proven, cost-effective and energy-efficient solution for delivering electricity and heat. Renewable sources provide clean and secure fuels for producing electricity and heat.

Co-generation and renewables: solutions for a low-carbon energy future shows that powerful synergies exist when co-generation and renewables work together. The report documents, for the first time, some of the little-known complementary aspects of the two technologies. It also re-emphasises the stand-alone benefits of each technology. Thus, decision makers can use the report as a "one-stop shop" when they need credible information on co-generation, renewables and the possible synergies between the two. It also provides answers to policy makers' questions about the potential energy and environmental benefits of an increased policy commitment to both co-generation and renewables.