GE Energy

Driving a Resource Efficiency Power Generation Sector in Europe

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Contents

Executive Summary

Through our analysis of France, Poland and the UK, we have concluded that supply-side energy efficiency measures have the potential to make a significant contribution to the achievement of the EU's carbon emissions and primary energy savings targets.

In these three major member states, we estimate that supply-side options can contribute up to 35% of an overall goal of a 20% carbon emissions reduction and up to 30% of an overall goal to reduce primary energy consumption by 20%.

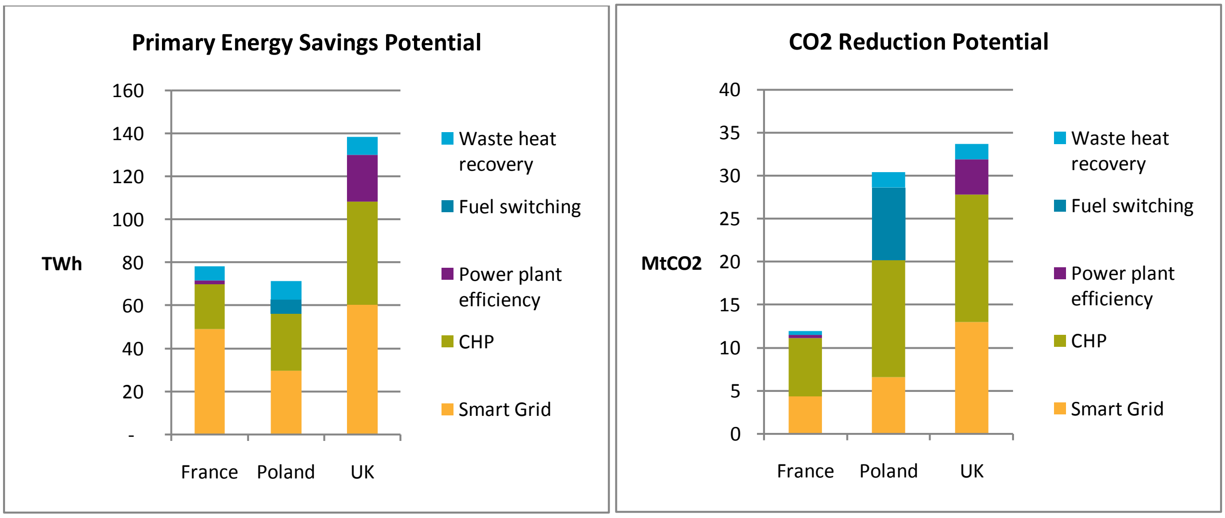
We have also identified a range of practical policy measures that can be implemented to ensure this potential is achieved.

GE Energy commissioned Delta to identify the economic potential for, and estimate the benefits of, supply-side efficiency options in three European countries – France, Poland and the UK. The technology areas covered by our analysis include:

- Fuel switching in the power sector – specifically from coal to natural gas.
- Power plant optimisation and other measures to improve the efficiency of existing CCGT power plants.
- CHP of all sizes and applications, from micro-scale residential to large-scale industrial.
- The Smart Grid - including continuous diagnostics of energy consumption in buildings, improved T&D operational efficiency, 'smart' demand and influencing customer behaviour.
- Waste heat recovery – capturing waste heat from gas engines and turbines, industrial processes and biomass boilers, and converting this heat to electricity.

The benefits of renewables and demand-side efficiency measures are now well understood among policymakers, and have rightfully received high priority, both at the EU and national levels. With the potential and benefits of some supply-side efficiency now becoming better understood, we believe that increased policy focus in this area, over and above the EU Emissions Trading Scheme (which in itself is unlikely to be sufficient to unlock the potential that we have identified), can enable some key EU energy and environmental objectives to be met more quickly and more cost-effectively. Figure 1 summarises our findings from the three countries.

FIGURE 1: PRIMARY ENERGY AND CO_2 SAVINGS POTENTIAL FROM SUPPLY SIDE EFFICIENCY MEASURES IN THE UK, FRANCE AND POLAND

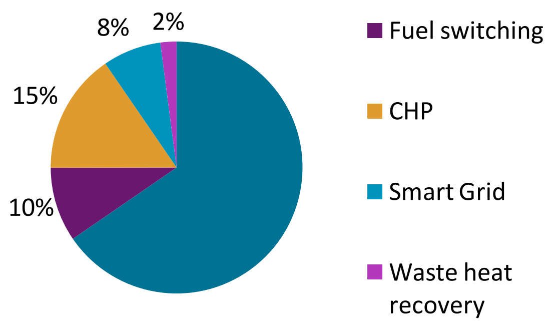
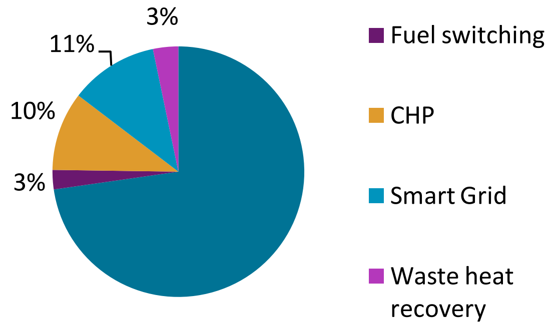


Source: Delta Energy & Environment

Poland

Poland stands out as having high potential to deploy some supply-side efficiency measures, and to great effect. By 2020, over one third of Poland's CO_2 reduction target could be met on the supply side.

FIGURE 2: POLAND - CONTRIBUTION OF SUPPLY-SIDE EFFICIENCY MEASURES TO 2020 CO_2 (LEFT) AND PRIMARY ENERGY SAVING (RIGHT) TARGETS

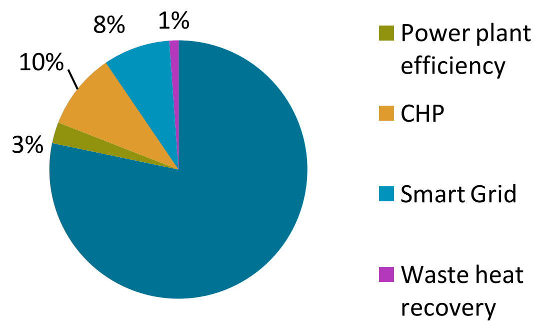
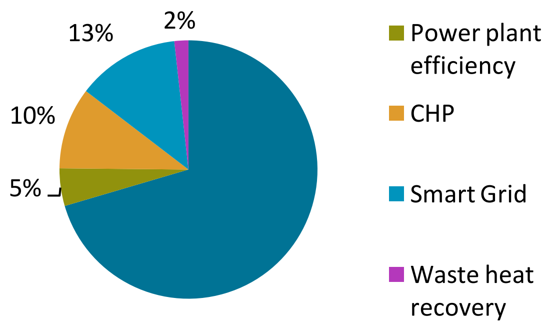
CO_2 savings	Primary energy savings
35% of CO_2 reduction target can be met by fuel switching, CHP, Smart Grid and waste heat recovery	**27% of PES target can be met by fuel switching, CHP, Smart Grid and waste heat recovery**
	

Source: Delta Energy & Environment

The UK

A policy push to achieve the potential from CHP and Smart Grid alone could see the UK meet almost one quarter of a 20% primary energy savings target and almost 20% of a CO_2 reduction target for 2020.

FIGURE 3: THE UK - CONTRIBUTION OF SUPPLY-SIDE EFFICIENCY MEASURES TO 2020 CO_2 (LEFT) AND PRIMARY ENERGY SAVING (RIGHT) TARGETS

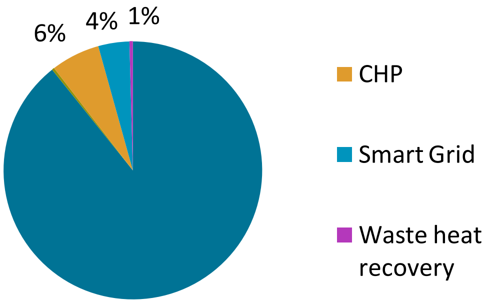
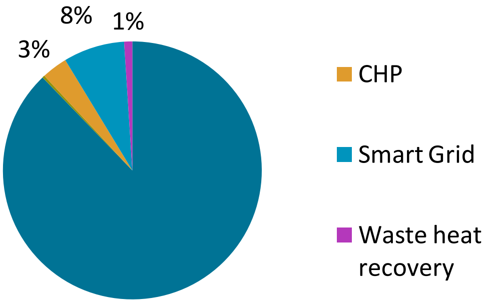
CO_2 savings	Primary energy savings
22% of CO_2 reduction target can be met by power plant efficiency, CHP, Smart Grid and waste heat recovery	**30% of PES target can be met by power plant efficiency, CHP, Smart Grid and waste heat recovery**
	

Source: Delta Energy & Environment

France

Three of the five supply-side measures that we have reviewed show significant potential – CHP, Smart Grid and waste heat recovery.

FIGURE 4: FRANCE - CONTRIBUTION OF SUPPLY-SIDE EFFICIENCY MEASURES TO 2020 CO_2 (LEFT) AND PRIMARY ENERGY SAVING (RIGHT) TARGETS

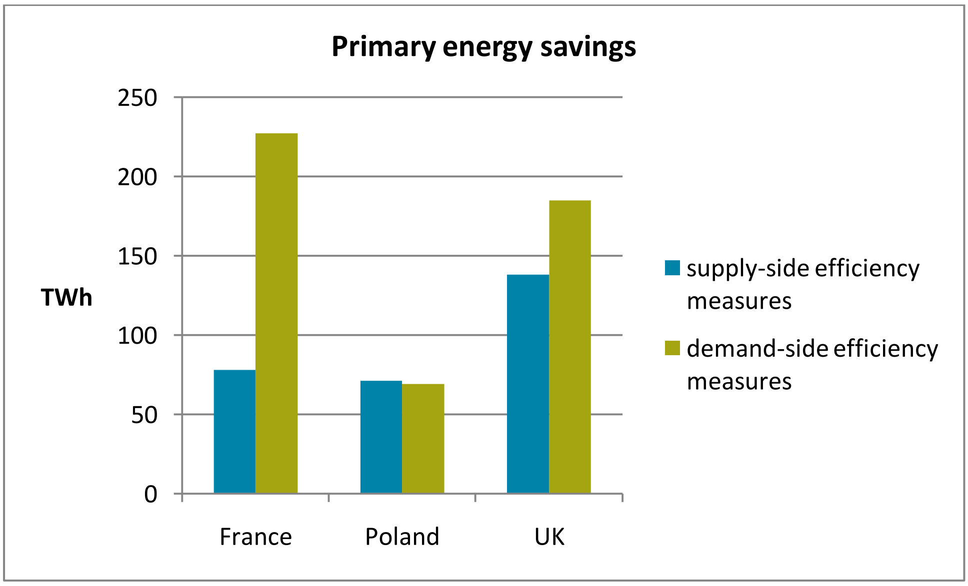
CO_2 savings	Primary energy savings
11% of France's CO_2 reduction target for 2020 can be met by CHP, Smart Grid and waste heat recovery  	**12% of France's PES target can be met by CHP, Smart Grid and waste heat recovery** 

Source: Delta Energy & Environment

Benefits on a par with demand-side measures

As part of our analysis, we have also compared the primary energy saving benefits of the supply side efficiency that we have assessed (there are other options that we have not assessed) with those of demand-side measures that the member states have identified over a similar time-frame in their 2007 National Energy Efficiency Plans. If we were to take a comprehensive range of supply-side measures into account, we believe that the benefits would exceed considerably those of demand-side measures in Poland and be similar in scale in the UK. The comparisons are shown in Figure 5.

FIGURE 5: ANNUAL PRIMARY ENERGY SAVINGS BY 2020



Source: Delta Energy & Environment

Employment impact – new European jobs

Achieving the potentials that we have identified for supply-side energy efficiency will clearly create employment, often involving new and highly-skilled jobs – each section of this report contains some sectors-specific data on this aspect. However, we believe that the quality of the employment impact data that we have sourced for this research, along with much of the data that exists for separate studies in other energy sectors, makes it hard to draw firm conclusions about net employment impacts of one form of energy technology against another.

What we can be more confident about is that many of the supply-side technical measures that we have described in this report are sectors in which European-based companies and industries are strong, and in some cases world leaders.

1 Fuel switching

TABLE 1: SUMMARY OF THE POTENTIAL AND BENEFITS FOR FUEL SWITCHING FROM COAL TO GAS CCGT IN KEY MARKETS

	UK	France	Poland
Current generation mix – installed capacity	~29 GW coal ~25 GW gas ~11 GW nuclear	~7 GW coal ~7 GW gas ~63 GW nuclear	~30 GW coal ~1 GW gas
Potential for fuel switching	We assume that closing coal capacity can be replaced by a combination of renewable and gas CHP, not gas CCGT.	We assume that closing coal capacity can be replaced by a combination of renewable and gas CHP, not gas CCGT.	A potential for about 30% (4.1 GW) of the existing coal, scheduled for closure by 2020, to be switched to gas CCGT.
Benefits	-	-	Saving of 8.4Mt CO_2/yr (a 9.5% contribution to the 2020 target). Primary energy savings of 6.5 TWh/per year (a 2.5% contribution to 2020 target). 4,000 new jobs in construction, O&M.
Barriers	-	-	Energy security concerns Economic impacts New gas infrastructure requirements
Recommend-ations	-	-	These include: Continued diversification of the gas supply Encouraging investment in gas pipeline infrastructure though appropriate tariff policy.

Source: Delta Energy & Environment

1.1 The scope for fuel switching

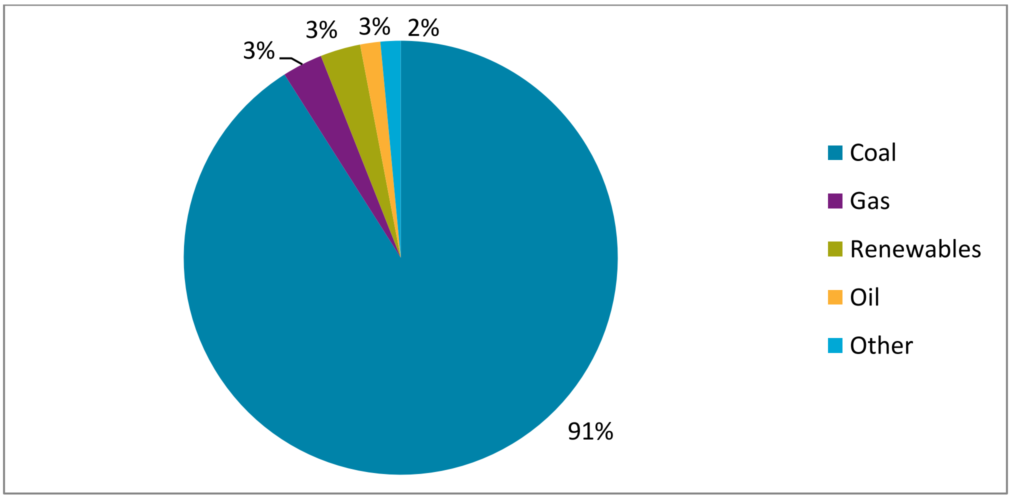
In some countries, there is a potential for increasing supply-side efficiency and reducing carbon emissions by replacing closing coal generation with new gas CCGT generation. Coal power plants emit around twice as much CO_2 per kWh of generation as gas-fired CCGT. New CCGT plants are also more efficient than coal plants, so reducing overall fuel use. The typical operational efficiency of a new gas CCGT is ~50%, while a 25 year old coal plant may have a typical operational efficiency of around 35%, often less.

1.2 Poland

Current generation mix

Polish electricity generation is dominated by coal power plants with over 90% generation from coal (see Figure 6)

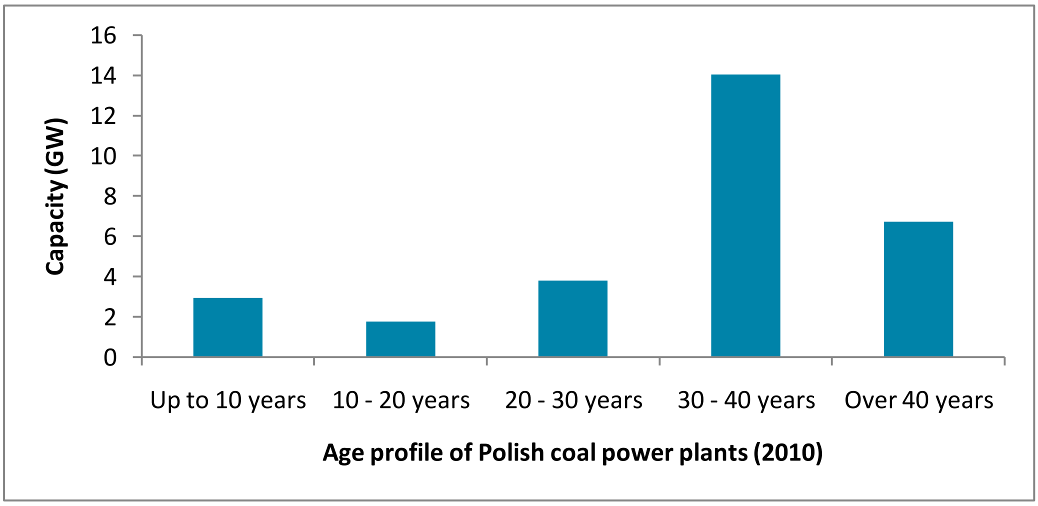
FIGURE 6: 2007 POLISH ELECTRICITY GENERATION MIX (%) – COAL DOMINATES



Source: World Bank 2011, IEA 2011, EU 2010

Poland has an aging generation base; a majority of existing capacity is over 30 years old (see Figure 7). Since 1990, only 7.5 GW of new generation has been built – all of which has been coal (IEA 2011, Citigroup Global Markets 2010).

FIGURE 7: AGE STRUCTURE OF POLISH POWER PLANTS – MAJORITY OVER 30 YEARS



Source; IEA 2011, Citigroup Global Markets 2010

The potential for fuel switching

To determine the economic potential for fuel switching, we need to understand the decommissioning schedule for existing coal plants and estimate any increase in generation that will be required to meet projected additional demand in 2020. This way we can identify the 'generation gap' that needs to be bridged through a combination of new coal, new gas CCGT, new gas CHP and renewables (no new nuclear is projected to come on-stream before 2020, IEA March 2011):

- **Decommissioning schedule:** By 2020 around 13.5 GW of installed coal capacity (40% of the existing fleet) is likely to be decommissioned, resulting in lost generation of around 68 TWh.
- **A demand increase:** By 2020, we expect national electricity demand to increase by around 12.4 TWh (IEA 2011, EU 2010) above the 2010 level.

In total, therefore, we estimate that around 80 TWh of new electricity generation will be required in Poland by 2020.

To assess a realistic potential for new CCGT, we have assumed the following:

- **National renewable energy targets will be met:** Poland has a binding target to meet 15% of energy demand from renewables by 2020, which includes a target for a 19% share of total electricity generation. This equates to around 26 TWh of new renewables generation by 2020.
- **Coal plant already under construction will be built:** Around 2.6 GW of new coal is already under construction (IEA March 2011), providing about 13.1 TWh of electricity in 2020. We assume that this will be completed, but that no other new coal plant will be constructed.
- **High efficiency gas-fired CHP can have an important new role**: CHP is already well-known in Poland, with many existing coal plants providing district heat. Chapter 3 of this report has identified a 2020 potential of around 20.0 TWh of new gas-fired CHP electricity generation.

Taking these assumptions into account, we estimate that there is both technical and economic potential for around **20.9 TWh of new generation based on CCGT,** equivalent to about 4.1 GWe of new capacity. The figure below provides a summary of Delta's view of realistic potential for fuel switching to gas CCGT in 2020.

Delta's view of realistic potential

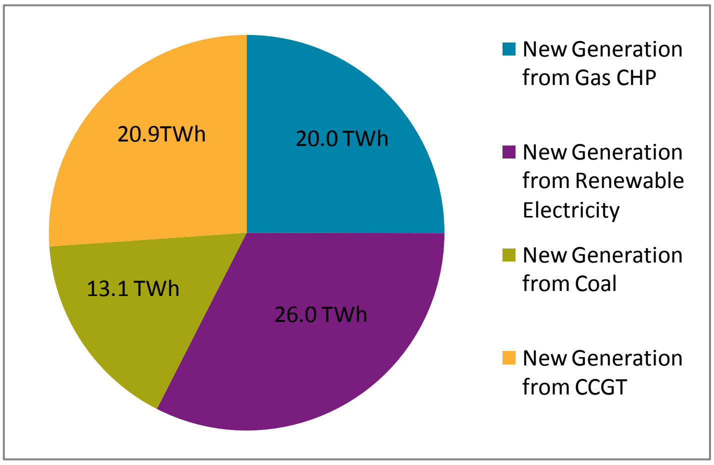
Generation gap 2010 - 2020:

- **Increase in demand:** 12.4TWh
- **Decommissioned coal:** 67.6 TWh
- **Total:** around 80 TWh

How it can be filled:

- **Coal:** 13.1 TWh
- **Gas CCGT**: 20.9 TWh
- **Gas CHP:** 20.0 TWh
- **Renewables:** 26.0 TWh

FIGURE 8: NEW GENERATION SOURCES, 2010-2020



Source: Delta Energy & Environment 2011

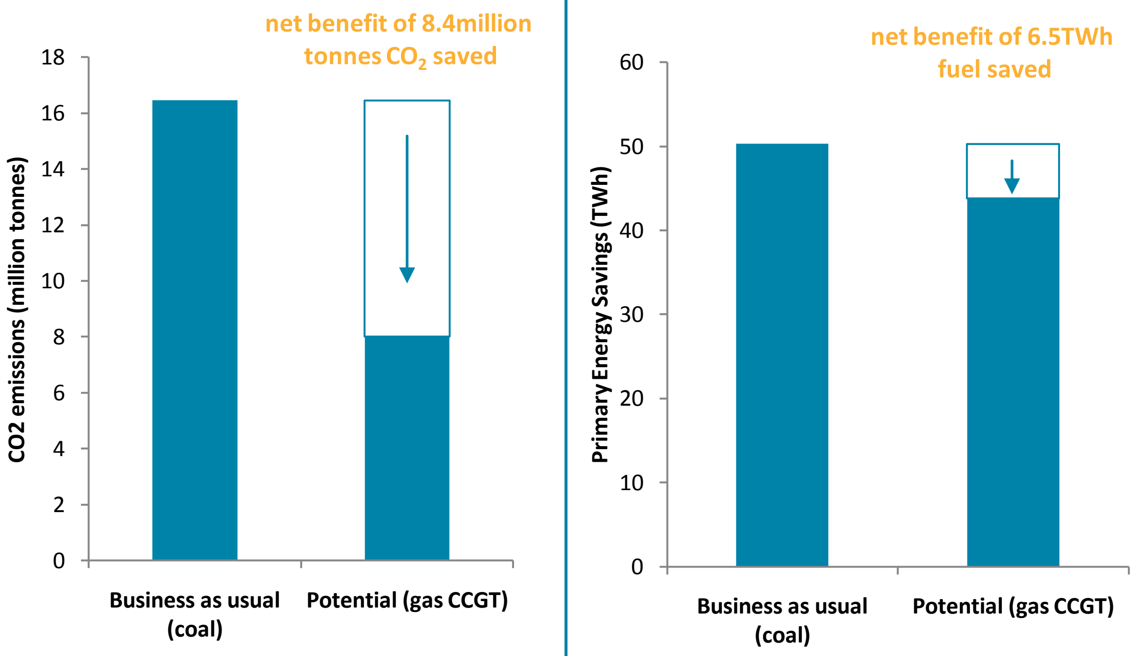
Benefits

To calculate the energy saving and carbon benefits of the approach we have described, we have compared our scenario with an alternative business-as-usual scenario in which new coal generation is developed instead of new CCGT to provide around 20.9 TWh of new generation. Our assumptions on the average 2020 operational efficiencies of each type of plant are 48% for new gas CCGT and 41% for new coal based on conversations with industry professionals.

Figure 9 summarises the comparison.

FIGURE 9: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH FUEL SWITCHING IN POLAND

CO_2 Savings	Primary energy savings
CO_2 savings are significant	**Fuel savings are more modest**



- This partial shift towards gas-fired CCGT can generate high CO_2 savings, even with significantly increased coal plant efficiencies by 2020.
- Gas CCGT could be a highly cost-effective means of reducing emissions by 2020.

- The fuel benefits of using new CCGT as opposed to new coal plants in 2020 are based on the relative efficiencies of the two types of plant.

Source: Delta Energy & Environment

Table 2 below summarises the potential contribution of fuel switching to the achievement of national targets.

TABLE 2: FUEL SWITCHING'S POTENTIAL CONTRIBUTION TO NATIONAL CO_2 AND PRIMARY ENERGY SAVINGS TARGETS

Potential CO_2 savings from fuel switching		**Potential primary energy savings from fuel switching**	
Total potential for CO_2 savings ($MtCO_2$/year)	**8.4**	**Total potential for energy savings (TWh/year)**	**6.5**
20% reduction required by 2020 in Poland ($MtCO_2$)	88	20% of 2020 forecast primary energy consumption (TWh)	261
Fuel switching contribution to CO_2 target (%)	***9.5%***	***Fuel switching contribution to energy saving target (%)***	***2.5%***

Source: Delta Energy & Environment

New jobs

Building the 4.1 GW of new gas CCGT plant that we have assumed will generate around **4000 new jobs in construction, operation and maintenance of the plant** (Wei et al 2010).

There will also be additional indirect job creation in associated industries, including in upgrading the gas network, building additional gas storage and, potentially, the exploration and production of domestic gas resources.

1.3 France and the UK

By applying the same methodology as we have used for Poland to the UK and France, we have come to the view that there is no realistic potential for new CCGT once we have included new gas-fired CHP and new renewables in the 2020 generation mix. In general, we believe that the optimal strategy for using natural gas in the power sector is to prioritise high efficiency CHP, for which there is high remaining economic potential in all countries, and only to trigger new CCGT investment where the economic potential for CHP is exhausted – as is the case in Poland.

1.4 Barriers

These barriers refer only to Poland, as there is no fuel switching potential in the UK or France.

Political context

Poland is already highly dependent on imported gas, **over 80% of gas imports come from Russia** (IEA 2011). Although the government is exploring ways to diversify supply, it signed an agreement last year for an increased supply from Russia until 2022. However, in addition to diversifying external supply there are a number of measures that could be taken to improve gas security, including:

- The development of domestic gas supply
- Continued upgrading of the gas transmission and distribution system
- Development of gas storage capacity.
- Construction of an LNG terminal.

Infrastructure requirements

Overall the gas supply structure in Poland is far less developed than it is for coal. If Poland commits to building some new CCGT plants, there may well be costs associated with developing domestic supplies of gas, upgrading the gas transmission and distribution network and increasing storage capacity.

Conversely, the up-front and O&M costs of CCGT are lower than for new coal plants. In this sense, investment in new CCGT represents a highly cost-effective means for reducing Poland's overall costs of carbon abatement.

1.5 Recommendations

These recommendations refer only to Poland, as there is no fuel switching potential in the UK or France.

Options for recommendations in relation to Polish fuel switching potential: Delta recognises the strong rationale for maintaining energy security of supply through the use of indigenous coal production. However, we believe that energy security can be maintained while enabling the replacement of some of the closing coal by new gas CCGT through, for example:

- Continued diversification of the gas supply
- Encouraging investment in gas pipeline infrastructure though appropriate tariff policy
- Developing a plan to manage and extract domestic gas resources
- Creating investment incentives for expanding gas storage capacity
- Continued liberalisation of the gas market
- Construction of LNG Terminals.

2 Power plant efficiency

TABLE 3: SUMMARY OF POTENTIAL AND BENEFITS FOR POWER PLANT EFFICIENCY IMPROVEMENTS IN THE THREE MARKETS

	UK	France	Poland
Potential for power plant efficiency improvement	▶ Significant potential, 50% of the CCGT capacity is >12 years old. ▶ The coal fleet has potential for improvements but these are unlikely to go beyond regulatory requirements.	▶ Very little CCGT plant. A small amount of potential – the bulk of which will be in the CCGTs >12 years old. ▶ Very little coal plant. The coal fleet is likely to close over time so there is little potential or political drive to improve efficiency.	▶ No CCGT ▶ In the large aging coal fleet, the realistic potential is small because very old plants will be replaced rather than improved.
2020 Benefits	▶ **4.1 Mt CO_2 saved / yr** ▶ 22 TWh fuel saved	▶ **0.34Mt CO_2 saved / yr** ▶ 1.9 TWh fuel saved	▶ Limited savings possible given the 2020 scenario.
Technical options	▶ Technology upgrades: **Fuel saving: 1-2%** ▶ Performance monitoring for more efficient O&M practices: **Fuel saving: 0.1-4%** ▶ Planning dispatch & load patterns to optimise efficiency: **Fuel saving: 10s of %**		
Barriers	▶ An economic barrier to implementing significant technology upgrades ▶ Small efficiency gains (0.1%) tend not to be valued ▶ Dispatch patterns are not yet determined based on plant efficiency, so there is no incentive for plants to make small efficiency improvements ▶ The focus is on plant replacement rather than upgrade.		
Recommend-ations	▶ Incentivise implementation of efficiency measures in existing plants through, for example: ○ Higher carbon prices ○ Priority dispatch for more efficient plants. ▶ Implement regulatory measures which take into account optimising efficiency in dispatch planning.		

Source: Delta Energy & Environment

2.1 Power plant efficiency improvements

There are various options for making plant efficiency improvements in existing CCGT and coal plants. In this section, we focus on CCGT plants; for coal plants, we have taken the view that the main longer-term decarbonisation options are carbon capture and storage or plant closure, both of which would have carbon benefits in excess of plant efficiency improvements based on prolonging the lifetime of the plants.

These are designed to counteract the efficiency drop over plant lifetime. In more recent plants, implementation of some of these measures may lead to a net efficiency gain, while in older plant these measures will bring efficiency back closer to that of modern plants.

These measures are summarised in the table below. The first two measures – *technology upgrades* and *performance monitoring* - can be implemented today to counteract the efficiency drop over the plant lifetime (typically in the range of 2% efficiency loss over ~24 years), and are driven primarily by economics. The third measure, *altering dispatch patterns and controlling load*, is an issue with major potential efficiency gains, but has longer-term potential, and is more dependent on policy and incentives.

TABLE 4: MEANS OF IMPROVING POWER PLANT EFFICIENCY

Type of improvement / Savings	Description
(i) Technology upgrades **Fuel / CO_2 saving: 1-2%**	*Upgrading components & systems* for increased efficiency, e.g. to optimize gas turbine output; to increase plant efficiency at part load and at start-up.
(ii) Performance monitoring – influence on O&M practices **Fuel / CO_2 saving: 0.1-4%**	*Modern power plants have accurate performance monitoring capabilities, but in less modern plants (> around 6 years old) there is scope for improvement,* enabling more efficient operational and maintenance practices. Performance monitoring relies on: (1) *More regular performance testing* by performance test teams or onsite performance engineers, and (2) *Implementation of automated performance monitoring equipment.*
(iii) Dispatch & load patterns **Fuel / CO_2 saving: 5-10% (and potentially as much as 20%)**	*Planning dispatch and running patterns to maximise efficiency* has large efficiency benefits, i.e. *by minimising plant cycling* (the number of times a plant switches on / off) & the *length of time at part load*.

Source: Delta Energy & Environment

Types of technology upgrades

There are a suite of technology options for improving the efficiency of CCGT plants, which optimise the control of the thermodynamic cycle, or minimise leaks and losses. These mechanisms will be standard in most modern power plants, but for plants of around 6 years or more, implementation of these measures can bring a plant close to the efficiency of a new build plant. The range of efficiency improvements achievable is from 0.5% to around 2% for a plant half way through its life (~12 yrs). A very old and inefficient plant may benefit from improvements of up to 5% from such measures. Figure 10 illustrates this.

FIGURE 10: EXAMPLES OF MECHANISMS FOR IMPROVING CCGT PLANT OUTPUT

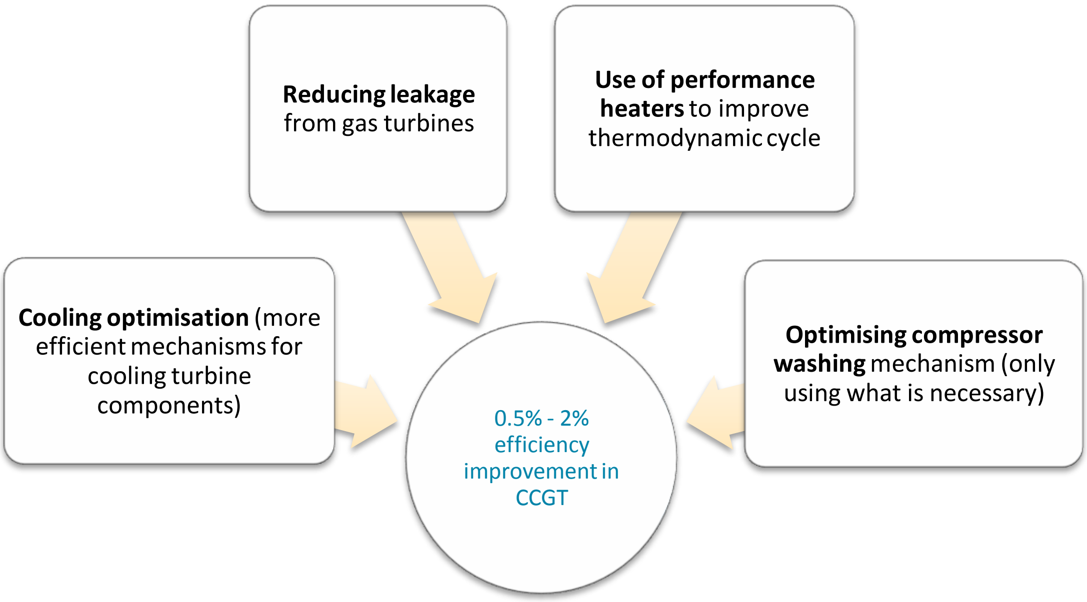


TABLE 5: OTHER TECHNOLOGY UPGRADES WITH EFFICIENCY BENEFITS FOR CCGT PLANTS

Improving efficiency at part load	Fast start – reduces fuel consumption on start-up by half
▶ With a growing trend towards greater cycling of plants (based on increasing shares of inflexible renewable and nuclear generation); it is increasingly important to increase part-load efficiency. ▶ 2% heat rate improvement at 50% load.	▶ With daily start up plants, **5-10%** overall efficiency gains could be made. ▶ If start up is only every few weeks or months, the gains could be **<0.5%.**

Source: Delta Energy & Environment

2.2 UK

Key Message

- A significant opportunity for power plant efficiency improvements in the UK lies in the CCGT fleet – particularly that which will be aged > 12 years by 2020.

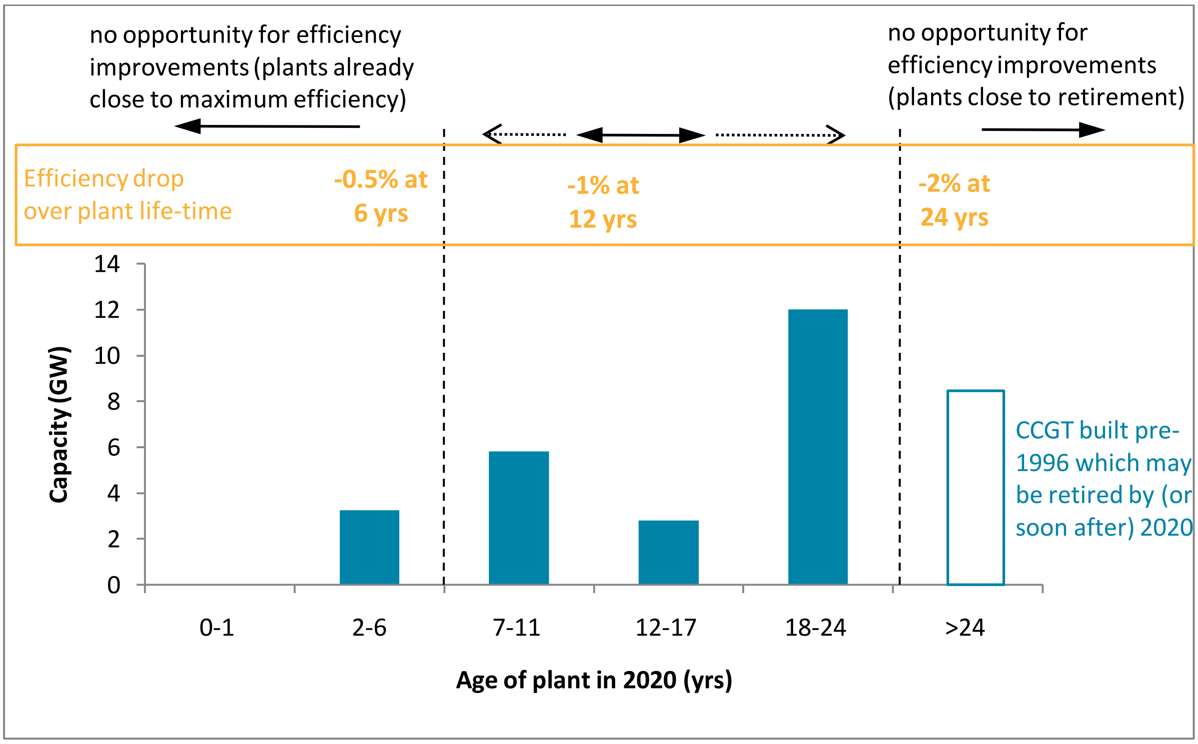
2020 potential for efficiency improvements

Current UK electricity demand is met primarily by fossil fuels with a growing proportion of nuclear and renewables. The existing CCGT fleet is significantly younger than the coal fleet - it has all been built since the 90s, and ~70% of it is likely to still be operational in 2020. The coal fleet is ageing and 95% of capacity has run for more than 24 years and, as we have explained, is not part of our analysis here.

In our analysis of the CCGT efficiency opportunity, we have assumed a 2% drop in efficiency over 24 years of plant operation. The efficiency measures we describe here will go some way to compensate for this efficiency drop.

To assess the potential for efficiency improvements in the UK fleet, we have analysed its age profile to identify those plants where there is scope for efficiency improvement. As Figure 11 shows, over half of the CCGT fleet will be more than 12 years old by 2020. In our assessment of the potential energy savings, we assume that all plants aged 12 and over receive the maximum energy efficiency improvements.

FIGURE 11: PROJECTED AGE PROFILE OF UK CCGT PLANTS IN 2020



Source: DUKES, 2010; New Power, 2010; Delta Energy & Environment, 2011

There are three major areas where efficiency gains can be made in UK CCGT – (1) through upgrading the technology and implementing efficiency measures, (2) through more accurately monitoring plant performance – enabling more efficient maintenance and operational practices, and

(3) through altering the overall dispatch patterns to optimise plant efficiency. The table below summarises the scale of the opportunity for elements (1) and (2), and element (3) is discussed separately in the text box below.

TABLE 6: POTENTIAL FOR EFFICIENCY IMPROVEMENTS IN DIFFERENT AGE RANGES OF UK CCGT PLANT IN 2020

The assumptions around this analysis are outlined in **Annex 1**. **Key:** Red = <5% of the potential efficiency measures are achieved; Amber = 5 - 50% of the potential efficiency measures can be achieved; Green = 50-100% of the potential efficiency measures can be achieved. In Delta's analysis, we assume that all plants receive maximum efficiency measures at aged 12 – so all plants aged 12 or over in 2020 have had full efficiency improvements made.

Measure		**Age of plant**				
		<6 years	**6-12 years**	**12-18 years**	**18-24 years**	**>24 years**
Proportion of UK CCGT plants of age		24%	21%	10%	44%	0%
Measure	Technology upgrade: gas turbines 0.5-2% gain	🔴	🟠	🟢	🟠	🔴
	Technology upgrade: efficiency at part-load & at start-up 0.1-5% gain *(dependent on operational regime)*	🟠	🟢	🟢	🟠	🔴
	More accurate performance monitoring 0.1-2% gain	🔴	🔴	🟢	🟢	🔴

Source: Delta Energy & Environment 2011

Alternative approaches to planning dispatch patterns: Potential for efficiency gains

Dispatch patterns of power plants – how often they cycle on and off – are key to determining CCGT plant efficiency. During plant start-up, more fuel is consumed than during running – so a plant cycling on and off every day could consume as much as 20% more fuel per kWh of electricity output than a plant running at baseload.

This efficiency loss from CCGT is set to become more of an issue in the UK. **The shift towards a low carbon future - involving increased growth in inflexible nuclear baseload and intermittent renewables – means that CCGT will have to shift to increasingly cyclical operation.** Annex 1 (Figure 29) outlines Delta's assumptions for how the CCGT fleet will be influenced by this trend. There will be an increasing proportion of CCGT running in cycling operation (as mid-merit and peaking plant), and a reduced proportion running as baseload.

In most EU markets, the UK included, planning of dispatch patterns is not based on avoiding cycling operation in order to optimise plant efficiency, but on economics. If dispatch planning took this into account as the UK shifts towards increasingly cyclical operation of CCGTs (for example allowing plants to keep running at a lower level rather than cease running completely) significant efficiency gains in the order of 5-10% could be made in the UK CCGT fleet. Assumptions are outlined in **Annex 1**.

Benefits of efficiency measures in existing CCGT plants: fuel and CO_2 savings

As the table below summarises, our analysis of the realistic potential for implementation of efficiency measures in the CCGT fleet can save the UK about 6.9 TWh of primary fuel input, and about 1.26 Mt of CO_2 per year.

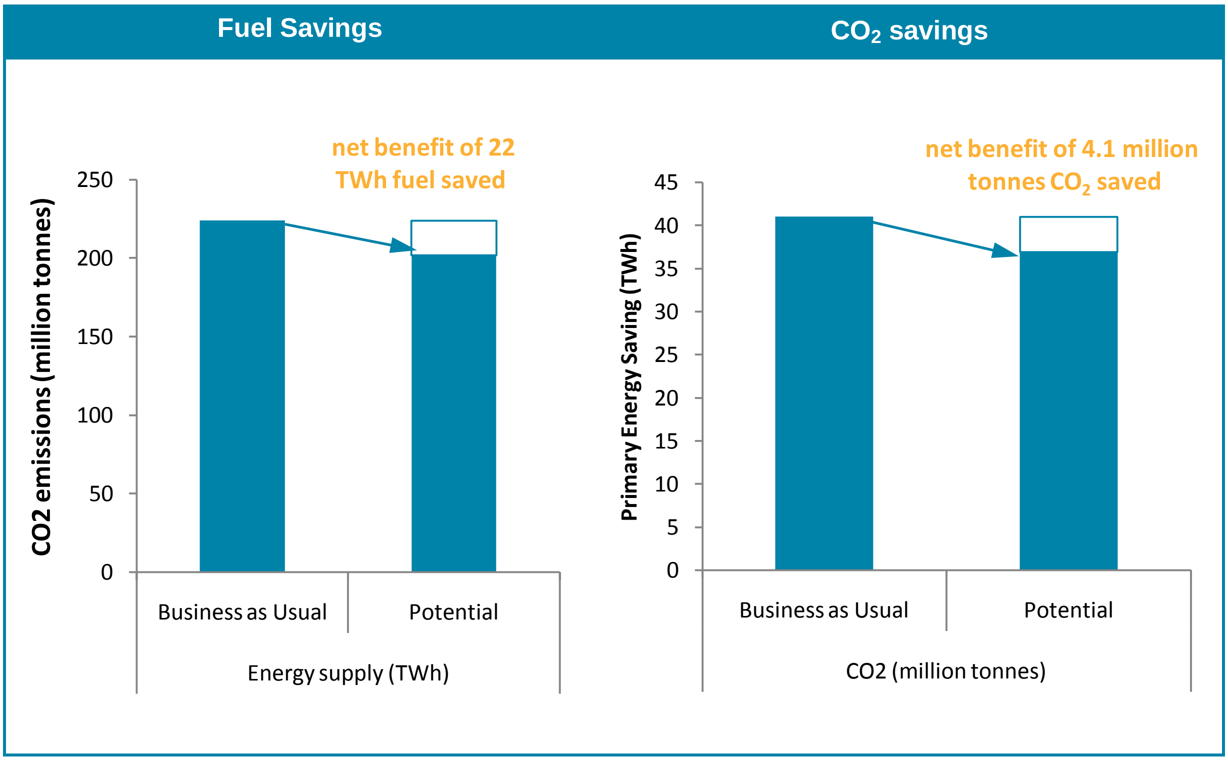
TABLE 7: CARBON AND ENERGY SAVING BENEFITS FROM PLANT EFFICIENCY MEASURES

	Potential
Fuel input to 2020 CCGT fleet with no efficiency improvements (BAU)	224 TWh
Fuel input to 2020 CCGT fleet after implementation of efficiency improvements	202 TWh
Fuel (natural gas) saving by implementing efficiency measures / yr	**22 TWh**
Contribution to energy saving target	*4.8%*
CO_2 savings by implementing efficiency measures / year	**4.1 Mt**
Contribution to meeting national 20% CO_2 target	*2.6%*

Source: Delta Energy & Environment

In Figure 12, we illustrate this reduction in primary fuel input to CCGT plants, and the associated CO_2 emissions reduction, as a result of implementing plant efficiency measures.

FIGURE 12: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH IMPLEMENTING EFFICIENCY MEASURES IN UK CCGT PLANTS



Source: Delta Energy & Environment 2011

There is as yet no reliable data or research for quantifying the jobs benefits of implementing efficiency measures in existing plants.

2.3 France

Key Message

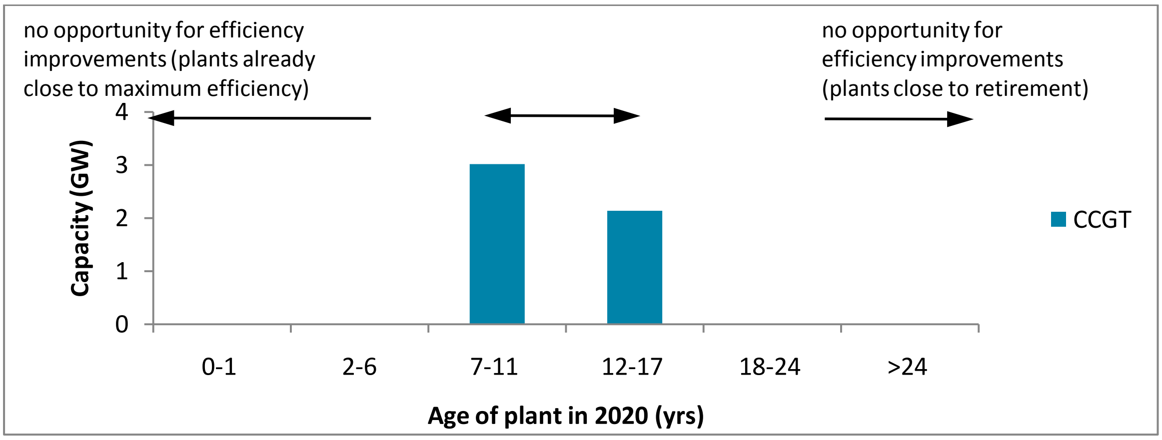
- There is only limited opportunity for improvements to CCGT plants that which will be aged > 12 years by 2020. The French CCGT fleet is young.

Analysis of potential for plant efficiency improvements in France

French generating capacity is dominated by nuclear, with an aging coal fleet (80% of which is over 40 years old), and a small, young CCGT fleet (all built since 2005, with 4 more under construction at present and due online by 2014. Again, we have not included coal plants in our assessments, for the same reason as given under the UK). See **Annex 1** for more details.

There is some limited potential for improvements to the 2 GW of CCGT plants which will be older than 12 years old in 2020.

FIGURE 13: PROJECTED AGE PROFILE OF FRENCH CCGT PLANTS IN 2020



Source: Data on existing & planned CCGTs - EDF, 2011; projection to 2020 - Delta Energy & Environment, 2011

Benefits of efficiency measures in existing plants: fuel and CO_2 savings

Due to the very small number of aging CCGT plants in France in 2020, and the initial high build quality, we believe that there is only limited scope for efficiency improvements to be made. These are summarised in the table below.

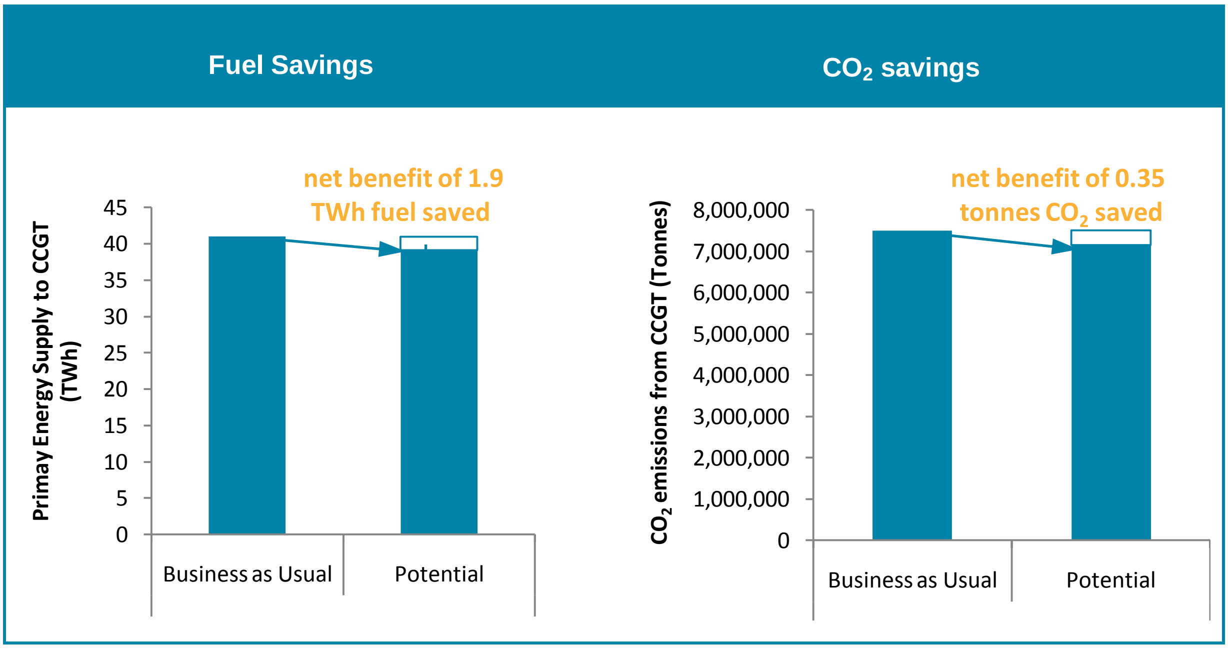
TABLE 8: SUMMARY RESULTS FROM DELTA ANALYSIS

	Economic Potential
Fuel input to 2020 CCGT fleet with no efficiency improvements (BAU)	41 TWh
Fuel input to 2020 CCGT fleet after implementation of efficiency improvements	39 TWh
Fuel (natural gas) saving by implementing efficiency measures / yr	**1.9 TWh**
Contribution to energy saving target	*0.3%*
CO_2 savings by implementing efficiency measures / year	**0.34 Mt**
Contribution to meeting national CO_2 targets	*0.3%*

Source: Delta Energy & Environment

In Figure 14, we illustrate this reduction in primary fuel input to CCGT plants, and the associated CO_2 emissions reduction, as a result of implementing plant efficiency measures.

FIGURE 14: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH IMPLEMENTING EFFICIENCY MEASURES IN FRENCH CCGT PLANTS



Source: Delta Energy & Environment 2011

2.4 Poland

Key Messages

No real potential for plant efficiency measures in Poland because of:

- Aging coal fleet
- Very small, young CCGT fleet by 2020

Analysing potential for efficiency improvements in Poland in 2020

The Polish power sector is dominated by an aging coal fleet, which will be gradually retired and replaced over the next 10-15 years (30% of capacity is due to be retired by 2016). The focus is on new build and fuel switching rather than improving aging coal plants.

However, a small amount of CCGT will have come online by 2020, but this will be so young that there will be no real efficiency gains to be made. More information on the current status of Polish generation and the projected 2020 age profile of plants can be found in **Annex 1**.

2.5 Barriers

We have identified some potential for efficiency gains in Europe's growing fleet of CCGT power plants, but also some real prospect that these gains may not be achieved.

- The main challenge is the economic rationale for investing in existing plants. Neither the operation of Europe's electricity markets nor the level of the carbon price is sufficient to incentivise plant owners to invest in efficiency improvements.
- There is insufficient economic incentive to invest in more sophisticated performance monitoring regimes – meaning that potential efficiency losses are not identified, and therefore not addressed.
- Currently, the market operates in such a way that plants are generally dispatched on the basis of cost rather than on the basis of energy or carbon efficiency.

2.6 Recommendations

We propose the following options for measures that can be implemented to deliver the potential we have identified:

- Incentivise the implementation of efficiency measures in existing plants.
- Incentivise more rigorous performance monitoring to identify & minimise efficiency losses.
- Develop a regulatory regime which takes into account the optimising of plant efficiency in dispatch planning, especially given the European shift that is taking place from base-load thermal plants to a need for a more flexible type of operation, in response to greater shares of inflexible renewable and nuclear generation, which has negative impacts on plant efficiency.

3 Combined Heat and Power (CHP)

TABLE 9: CHP - SUMMARY OF STATUS AND POTENTIAL FOR CHP

	The UK	France	Poland
Potential for CHP	▶ Potential for 6.3 GWe of new gas-fired CHP beyond BAU	▶ Potential for 2.6 GWe of new gas-fired CHP beyond BAU	▶ Potential for 2.6 GWe of new gas-fired CHP beyond BAU
Benefits	▶ 14.8 Mt CO_2 can be saved ▶ Energy savings of 47.9 TWh ▶ Potential for around 50,000 new UK jobs by 2020.	▶ 6.8 Mt CO_2 can be saved ▶ Energy savings of 20.7 TWh ▶ Potential for 100,000 new jobs per year across the EU by 2020.	▶ 13.6 Mt CO_2 can be saved ▶ Energy savings of 26.5 TWh ▶ Potential for 100,000 new jobs per year across the EU by 2020.
Barriers	General barriers include: ▶ **Regulatory challenges**: Complex and inconsistent interconnection and administrative procedures can delay projects and so increase costs ▶ **Lack of a full understanding of CHP benefits**: Policy makers, in general, do not fully recognise CHP's energy and carbon benefits ▶ **Investment uncertainty**: CHP usually needs a long-term stable heat load over a 10-15 year period. While complete certainty can never be achieved, the commercial risks facing CHP over a project lifetime are relatively high compared with power-only generation. There are also some country-specific barriers.		
Policy Recommend-ations	Options include: ▶ Introduce / increase modest utility supply obligations to guarantee a market for CHP electricity ▶ Make interconnection procedures more transparent and consistent ▶ Ensure that the CO_2 benefits of CHP are better reflected in EU emissions regulations ▶ Encourage local heat planning to create more stable heat loads for CHP.		

Source: Delta Energy & Environment

3.1 CHP today – contributing around 11% of EU electricity generation

CHP, also known as cogeneration, is the simultaneous production of electricity and heating (and sometimes cooling) from a single process. CHP systems are located at, or very close to, the point of energy use, and it is this feature that enables the heat, that is normally wasted in conventional electricity generation, to be recovered and used[1].

The user and type of heat defines the type of CHP application, of which there are several:

- **Micro-CHP** – very small systems (1 – 5 kWe) located in individual residential homes or in buildings with a small number of residential units. The CHP provides electricity, hot water, heating and / or cooling.
- **Commercial / institutional CHP** – also known as 'mini' and 'small-scale' CHP (larger than 5 kWe and up to around 1-10 MWe), located in light industry, supermarkets, public buildings, offices etc. The CHP provides electricity, hot water, heating and / or cooling.
- **Industrial CHP** – larger systems (1 – 500 MWe+) located in industrial facilities, with the CHP providing electricity and steam for process use.
- **District heating (DH) and cooling (DHC) CHP** – similar to commercial / institutional CHP, but provides heating / cooling to multiple buildings (including residential) connected together through a heat distribution network.

CHP is an established technology in Europe. Over 100 GWe of CHP is already installed across EU-27, and its share of total electricity generation is around 11% - it is a proven, cost-effective and reliable form of energy supply. Table 10 summarises the position of CHP today in the EU, across the three focus countries and, for comparison, in three countries where CHP is well developed (Denmark, the Netherlands and Finland).

TABLE 10 – CURRENT STATUS OF CHP IN THE EU AND SELECTED COUNTRIES.

	Installed CHP (GWe)	CHP as % of electricity generation	CHP - Gas share (%)	Coal share (%)	Other (incl renewable) share (%)
EU-27	100.2	11.0	39.4	34.8	25.8
Denmark	5.4	46.1	23.8	52.2	24.0
Finland	5.7	35.6	21.6	26.5	51.9
France	5.1	3.1	57.2	4.4	38.4
Netherlands	9.0	33.6	70.3	11.5	18.2
Poland	8.8	16.9	2.5	91.1	6.4
UK	5.5	6.4	70.5	4.3	25.2

Source: Eurostat 2010

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[1] For an introduction to CHP, its global benefits and potential, see 'Combined Heat & Power – Evaluating the benefits of greater global investment', produced by Delta Energy & Environment and published by the International Energy Agency as part of its CHP Collaborative Programme, 2008, www.iea.org.

The high degree of CHP penetration in some countries is an indication that the economic potential of CHP in the three focus countries (France, Poland, the UK), and across the EU as a whole, is likely to be higher, possibly significantly higher, than that achieved so far.

There is also a diverse fuel mix for CHP across all countries, reflecting historic fuel source choices. In general, gas-fired CHP is the norm for new CHP projects developed today, with an increasing focus on renewable-based CHP, using biomass and various biogases as the fuel.

CHP in France – nuclear power is the priority

CHP development in France has been limited due to relatively low electricity prices that are based on a large fleet of nuclear plants that were developed when the electricity sector was under full state ownership. The installed capacity for CHP today is 5.1 GWe, which supplies only 3.1% of total electricity generation

With nuclear dominating electricity generation in France, the government believes that that there is only limited scope for new CHP development in the future. While we believe that there is some significant remaining economic potential, CHP activity in France is likely to be restricted to maintaining and repairing existing plant unless policy is implemented to drive new market growth.

CHP in Poland – coal dominates

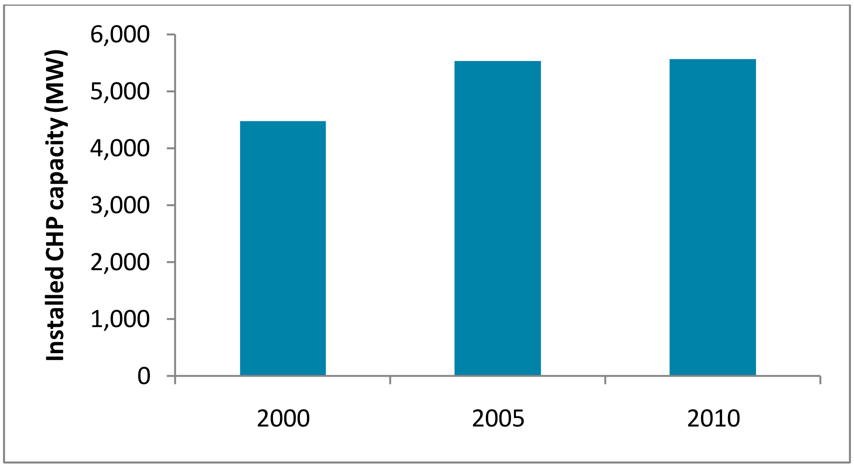
Polish electricity and heat supply is based predominantly from coal – with more than 90% of electricity generation in 2009 being from this fuel. Around 8.8 GW of CHP is installed today, delivering 16.9% of total electricity generation – with coal again being the predominant fuel used. Gas-fired CHP is currently limited to the south of the country where gas is more widely available. Most of today's CHP serves large DH networks.

With an aging coal fleet, and with energy security as a key priority for the Polish government, new coal and nuclear tends to be favoured as replacement capacity. CHP also continues to receive some support.

CHP in the UK – market stagnation since 2005

Today, 6 - 7% of total electricity generation in the UK comes from CHP. This has remained largely unchanged since 2005, with the market stagnating at around 5.5 GWe (Figure 15).

FIGURE 15: CHP INSTALLED CAPACITY IN THE UK



Source: Delta Energy & Environment

The UK market has struggled to develop further due mainly to:

- Market uncertainty around future policy support for CHP.
- The electricity market regulatory framework tends to favour smooth market operation rather than energy efficiency.

3.2 The 2020 potential for CHP

To understand the various benefits of the wider use of CHP by 2020, a solid understanding of the realistic potential for CHP is needed. Here, we focus on the potential for gas-fired CHP in particular. The reason for this is that the challenges facing the achievement of economic potentials are greater for gas-fired CHP, where barriers are greater and incentives are weaker, than for renewable-based CHP.

Indeed, we expect renewable-based CHP markets to develop strongly up to 2020, driven largely by the member state incentives that are being introduced to meet their commitments under the 20% mandated renewable energy targets. In short, there is every likelihood that the full economic potential for renewable CHP will be reached and exceeded by 2020. In this sense, the potential for renewable CHP is equivalent to a business-as-usual scenario (we also note that the greening of the Common Agricultural Policy can be enhanced by increased supply of biogas to high efficiency CHP systems).

Conversely, for gas-fired CHP the prospects are today much more problematic, with almost no EU-level incentive measures, and only very patchy member state level incentives. Hence the focus here is on understanding the economic potential for gas-fired CHP and, importantly, the challenges that are currently preventing this potential from being achieved. In this sense, we believe that the economic potential exceeds a business-as-usual scenario.

To identify and inform our view of the economic potentials for gas-fired CHP in 2020 in our three focus countries and across EU-27, we have used various sources, including:

- The European Commission's *Strategic Energy Technology Plan* (SEC 2007 1510).
- The European Commission's *EU Energy Trends to 2030* (2009 update).
- The International Energy Agency's *CHP – Evaluating the benefits of greater global investment* (IEA 2008).
- The *National Potential Studies* undertaken by EU Member States under the terms of the EU CHP Directive (2004/8/EC). These have been consolidated within the European Commission funded project, CODE - *Cogeneration Observatory and Dissemination Europe*. Each member state made its own assumptions to assess their national potentials.
- Eurelectric's *2010 European Power Statistics,* which includes projections to 2020 and 2030, with data provided by the major electric utilities in each member state.
- Various independent national studies.

Some of these sources are based simply on market projections under existing policies and measures. Others are based on a more ambitious analysis of what is technically and / or economically feasible. Some of these outputs are summarised in the table below.

TABLE 11: SELECTED POTENTIALS AND PROJECTIONS FOR CHP CAPACITY IN 2020 (GWE)

Source	France	Poland	UK	EU
EU Energy to 2030 (reference scenario)	5.8	10.3	8.7	Baseline – 115 GWe (18.4% of total power generation).
Eurelectric 2010	No data	6.4	11.0	140 GWe (aggregate member state data[2]).
IEA CHP Collaborative (accelerated CHP policies & measures).	2015 – 8.9 2030 – 16.9	-	2015 – 9.3 2030 – 18.4	-
EU SET Plan				Baseline - 160 GWe. Maximum – 185 GWe.
National Potential Studies (Economic and Technical Potentials)	Economic – 5.7 Technical – 30.0	Economic – an additional 8.8 GWe – i.e. c 17.6 GWe. In a separate natural gas scenario, additional potential of 20.5 GWe (see CODE).	Economic – an additional 10.6 GWe (by 2015) – i.e. c 16.1 GWe.	Additional economic potential of 122 GWe, giving total of 222 GWe in 2020.

Source: Delta Energy & Environment

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[2] The Eurelectric data is sourced from the national members of Eurelectric, consisting of Europe's major electricity companies. We believe that this figure is likely to represent a lower end forecast of what is feasible.

Building on these diverse sources, our view of the economic potentials are summarised in the box below.

Delta view on economic potential for CHP - 2020

France

- The national potential study indicates a low figure of 5.7 GWe by 2020. We have used this for our BAU assumption.
- Delta assumes an economic potential of 8.9 GWe based on IEA potential study which gave an equivalent capacity for the year 2015.

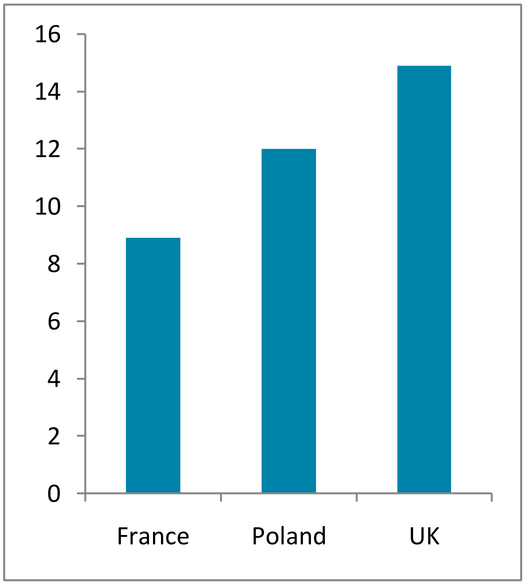
Poland

- The national study indicates an economic potential for an *additional* 8.8 GWe CHP by 2020, giving around 17.6 GWe in total.
- Delta believes new renewables will displace some of this potential, and assumes a potential for 12 GWe in 2020 – an additional 3.2 GWe.
- We have assumed no net growth in CHP for our BAU based on a combination of sources, including EU projections for only modest growth, and Eurelectric projections for a 20% *fall* in CHP capacity.

UK

- There is an economic potential for 16.1 GWe by 2020 indicated by the 2005 national study.
- Delta believes this is slightly ambitious, and assumes an economic potential of 14.9 GWe in 2020 – more in line with the IEA's analysis.
- We have assumed BAU development based on the historic 10 year trend.

FIGURE 16: DELTA VIEW OF THE ECONOMIC POTENTIAL FOR CHP IN 2020 (GWE)

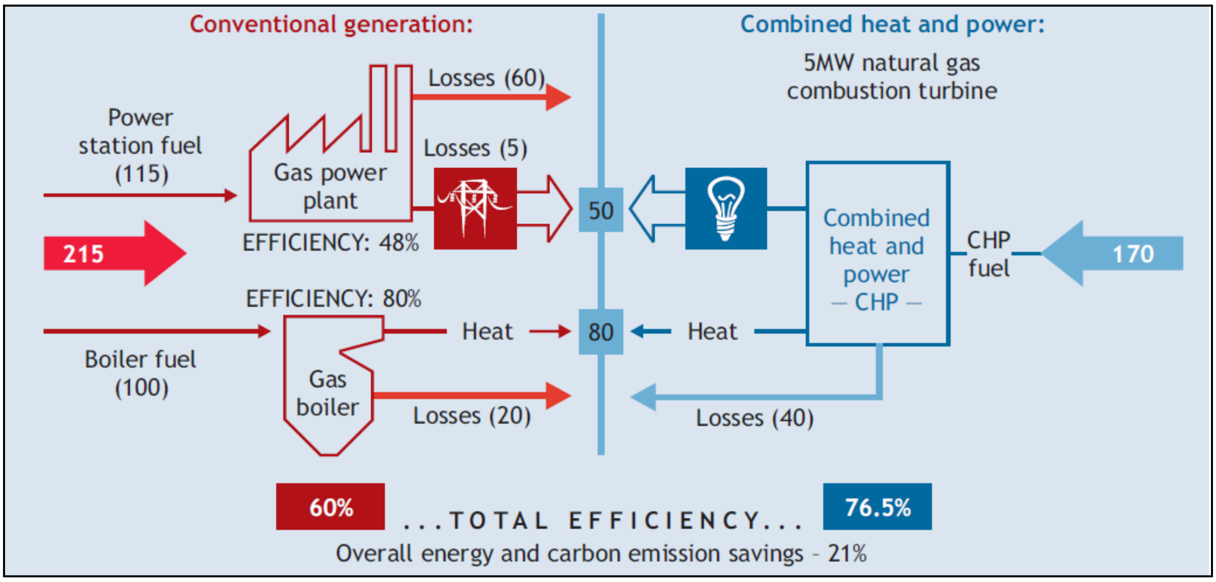


Source: Delta Energy & Environment

3.3 CHP benefits – significant carbon emissions and energy savings can be made

The degree of energy and carbon savings from CHP depends on the technology and fuel used in the CHP scheme and on the alternatives displaced. The technical characteristics of a CHP scheme are generally well defined, so the main uncertainty in assessing energy and carbon savings is in the fuel and efficiency assumed for alternative sources of the heat and power displaced. Figure 17 illustrates how CHP increases energy efficiency, and so reduces fuel use and cuts carbon emissions.

FIGURE 17 – EFFICIENCY GAINS FROM CHP – ILLUSTRATIVE EXAMPLE (ALL VALUES HHV, HIGHER HEATING VALUES)



Source: International Energy Agency, 2008

An additional benefit of CHP, not included in the illustration above, relates to its potential to contribute to electricity system supply / demand balancing. For example, through the use of heat storage systems, CHP in buildings can be scheduled to operate at times of electricity demand rather than heat demand. Industrial CHP systems also have the capacity to 'flex' their operation, through changes in its heat / power ratio, to generate more or less electricity depending on market prices.

Delta has modelled the CO_2 savings and energy savings for each of the three markets based on CHP achieving the economic potentials outlined above (our main assumptions for this modelling are given in **Annex 2**). The table below summarises the key data and benefits.

TABLE 12: BENEFITS RESULTS OF ACHEIVING CHP POTENTIALS

	France	Poland	UK
CHP potential in 2020			
Current CHP capacity (GWe)	5.1	8.8	5.5
2020 BAU installed CHP capacity (GWe)	5.7	8.8	7
CHP economic potential 2020 (GWe)	8.9	12	14.9
Difference between BAU and economic potential to 2020 – *stretch* (GWe)	3.2	3.2	7.9
Gas-fired CHP share of stretch (GWe) (the rest is renewable-based)	**2.6**	**2.6**	**6.3**
- **Share which is CHP in buildings / DH**	0.6	0.6	2.1
- **Share which is CHP in industry**	1.9	1.9	4.2
Potential CHP CO_2 savings			
Total CO_2 savings realised by building / DH CHP (Mt CO_2/year)	1.3	2.6	3.9
Total CO_2 savings realised by industrial CHP (Mt CO_2/year)	5.5	11.0	10.9
Total potential for CHP carbon savings in 2020 (Mt CO_2/year)	**6.8**	**13.6**	**14.8**
CHP contribution to achieving 2020 CO_2 targets			
20% reduction required by 2020 (Mt CO_2)	111	88	155
CHP contribution to CO_2 target (%)	***6.1***	***15.5***	***9.5***
Potential CHP primary energy savings			
Total energy savings realised by building / DH CHP (TWh/year)	3.8	5.0	12.0
Total energy savings realised by industrial CHP (TWh/year)	16.9	21.5	35.9
Total potential for CHP primary energy savings in 2020 (TWh/year)	**20.7**	**26.5**	**47.9**
Contribution to achieving 2020 primary energy reduction targets			
20% of forecast primary energy consumption (TWh)	640	261	468
CHP contribution to energy saving target (%)	***3.2***	***10.2***	***10.2***

Source: Delta Energy & Environment

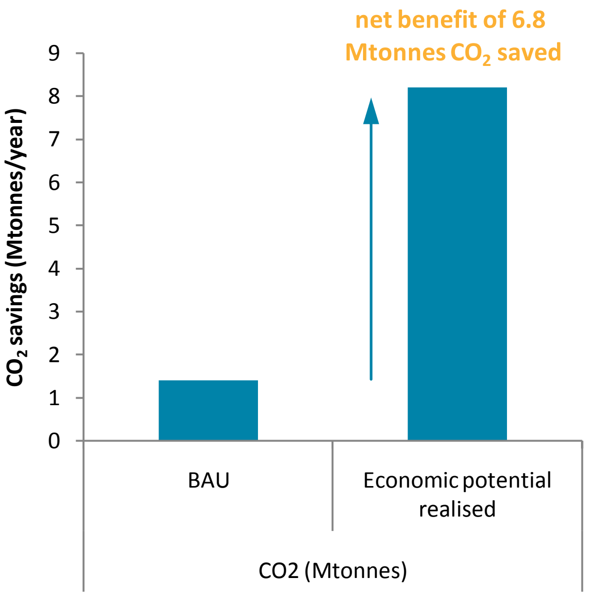
The benefits of CHP in France: CO_2 and energy savings

The figure below summarises the benefits of greater CHP deployment in France.

FIGURE 18: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH CHP DEPLOYMENT IN FRANCE

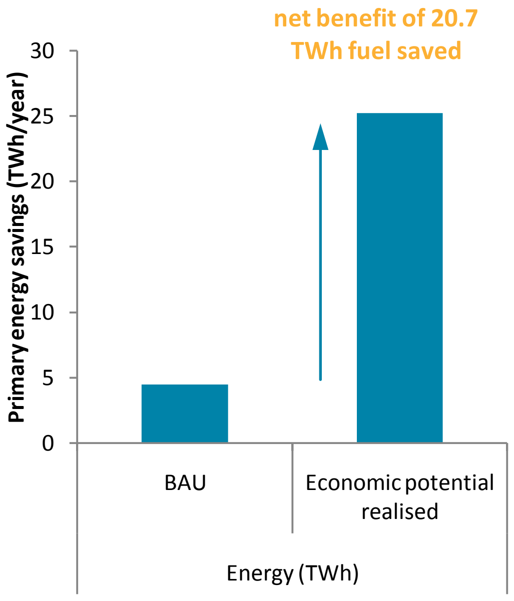
CO_2 savings

Realising Frances's full economic potential for gas-fired CHP delivers an additional 6.8 Mt of CO_2 savings. This is relatively small because of the strong position of nuclear generation in France.



Primary energy savings

Realising France's full economic potential for gas-fired CHP delivers an additional 20.7 TWh of primary energy savings.

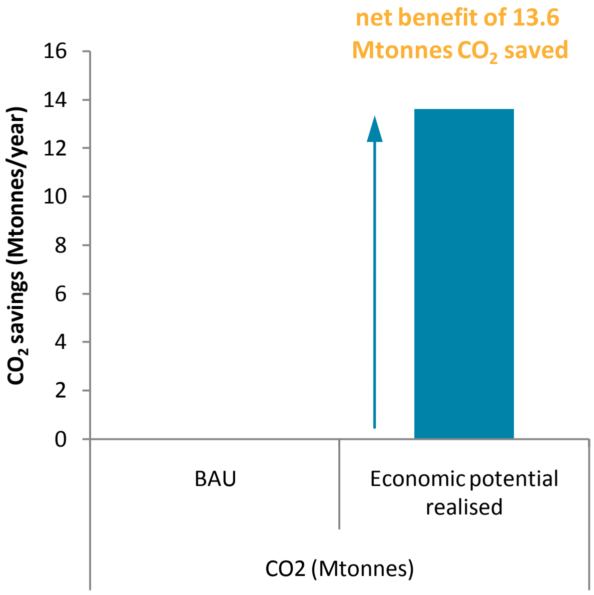
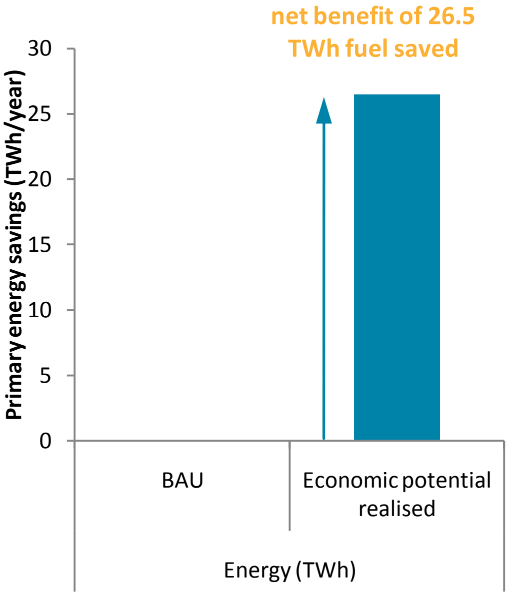


Source: Delta Energy & Environment

The benefits of CHP in Poland: CO_2 and energy savings

The figure below summarises the benefits of greater CHP deployment in Poland.

FIGURE 19: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH CHP DEPLOYMENT IN POLAND

CO_2 savings	**Primary energy savings**
The large penetration of existing coal generation in Poland means high carbon savings when replaced by gas-fired CHP – a potential of 13.6 Mt of CO_2 savings for 2.5 GWe new CHP – can be made by 2020 compared to the BAU scenario (no CHP growth).	Significant primary energy savings of 26.5 TWh can be achieved by gas-fired CHP compared to the BAU scenario (no CHP growth)
	

Source: Delta Energy & Environment

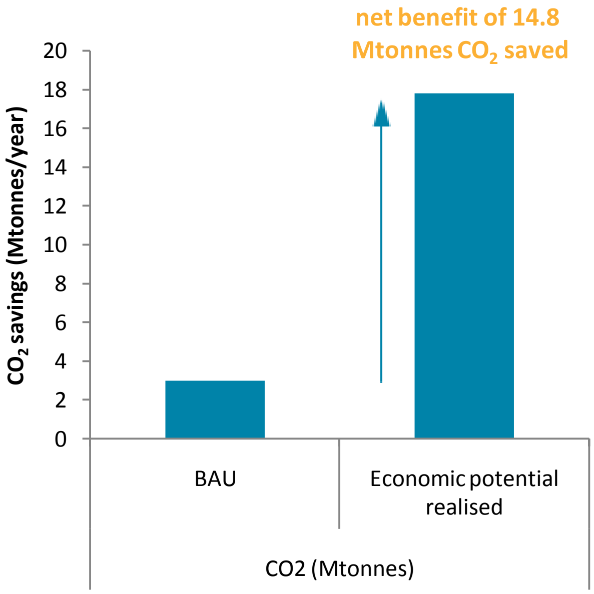
The benefits of CHP in the UK: CO_2 and energy savings

The figure below summarises the benefits of greater CHP deployment in the UK.

FIGURE 20: CO_2 AND FUEL SAVINGS TO BE MADE THROUGH CHP DEPLOYMENT IN THE UK

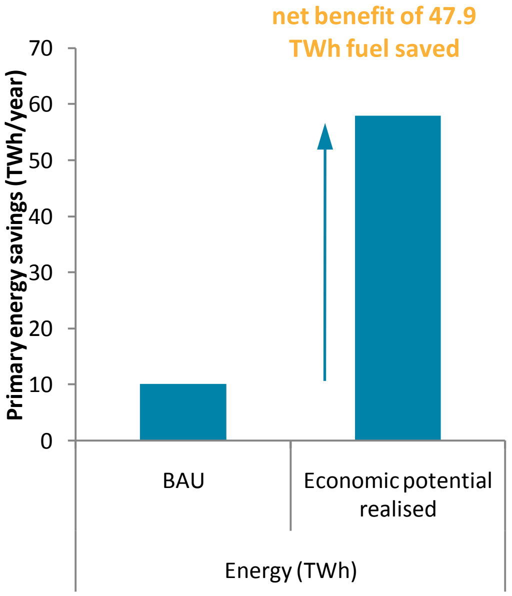
CO_2 savings

Realising the UK's full economic potential for gas-fired CHP delivers an additional 14.8 Mt of CO_2 savings.



Primary energy savings

Realising the UK's full economic potential for gas-fired CHP delivers an additional 47.9 TWh of primary energy savings.



Source: Delta Energy & Environment

3.4 The benefits of CHP: jobs

There has been little research undertaken into the employment impacts of new CHP development. The existing data is summarised in the table below.

TABLE 13: EXISTING DATA ON THE EMPLOYMENT IMPACTS OF CHP

Source	CHP employment impacts
EU	▶ Cogen Europe has estimated that the achievement of the EU's economic potential for CHP by 2020 would result in the creation of 100,000 new jobs per year.
France	▶ According to Club Cogénération, there are around 30,000 direct employees today in industrial CHP in France – amounting to 2.2 GW of industrial CHP. The employees carry out O&M activities. ▶ Based on Delta's assumption of an economic potential for a further 3.8 GWe of CHP, and extrapolating the existing jobs per GWe installed figure in French industry to DH & buildings CHP, this equates to around 50,000 permanent new jobs by 2020 for operating and maintaining new CHP plants.
UK	▶ Based on research undertaken for the UK CHP Association by Delta in 2009, the existing 5.5 GWe of CHP provides: ○ 5,000 jobs operating, developing and maintaining CHP plants. ○ 25,000 additional jobs in the supply chain. ▶ Based on Delta's assumption of an economic potential for a further 9.4 GWe of CHP and the existing jobs per GWe of CHP installed, the aggregate number of new jobs generated by 2020 will be around: ○ 8,000 – 9,000 jobs operating, developing and maintaining CHP plants. ○ 40,000 additional jobs in the supply chain.
CHP / DH	▶ The 1.2 GWth CHP DHC project in Mannheim, Germany, resulted in the creation of 4,000 new job years.
USA	▶ To achieve a growth in US CHP capacity from 85 GWe today to 240 GWe in 2030 (not dissimilar to some projections of the EU potential) will result in almost 1 million new jobs created by that year. This corresponds to around 6,400 new jobs per GWe of new CHP.

Source: Delta Energy & Environment

EU level benefits of CHP

By extrapolating the CHP benefits in these three major member states to an EU-27 level, on the basis of comparison of their combined final energy demand, we can derive an indication of the EU-wide benefits of CHP deployment on the basis that we have described here.

We find that gas-fired CHP can achieve around 328 TWh of primary energy savings and 113 Mt CO_2 / year of carbon emissions reductions by 2020 at the EU level. Thus gas-fired CHP alone (and not including renewable-based CHP) can potentially deliver around 8% and 10% respectively of the EU 20% objectives for both energy efficiency and carbon emissions.

3.5 Barriers

CHP has been successfully deployed in several markets across Europe, without the need for significant incentives. This success has largely been due to targeted policy support that has addressed key barriers – some of which are common across all European markets.

Common barriers to CHP development in Europe include:

- **Regulatory issues.** Interconnection procedures and administrative processes are often complex, inconsistent and time consuming, creating delay, and therefore additional cost, for developers of CHP.
- **Investment uncertainty.** CHP usually needs a long-term stable heat load over a 10-15 year period. While complete certainty can never be achieved, the commercial risks facing CHP over a project lifetime are relatively high compared with power-only generation.
- **Lack of awareness of CHP benefits.** A lack of understanding of the true value and benefits of CHP means it has not always been high up on political agendas, or received the necessary policy support to reach its full potential.
- **Challenge of incorporating CHP emissions benefits into European regulations.** Due to the combined generation of heat and power from a single process, it has proved hard to integrate the CO_2 benefits of CHP into the EU emissions trading scheme.

There are also market specific barriers in each country, for example:

- France: National energy policy has tended to prioritise nuclear power.
- Poland: there are concerns that the development of gas-fired CHP would unduly increase energy supply security concerns.
- UK: the regulatory framework for the electricity sector tends to prioritise smooth market operation over energy efficiency.

3.6 Recommendations

It is likely that modest policy measures would be sufficient to overcome these and other barriers to CHP development, and so enable the economic potentials to be achieved. There are several such options for policy recommendations that can be considered for implementation at EU and national levels. These include:

- **Energy supply obligations.** Through the set up of an obligation on electricity suppliers to source a certain proportion of their electricity from CHP, a market for new high efficiency CHP electricity can be accelerated. Such a system could become a part of a new EU wide White Certificate system.
- **Modest financial and fiscal support.** Increasing the financial/fiscal support for CHP can provide the additional push needed to enable CHP development, supporting countries in achieving their policy goals such as emissions reductions and energy efficiency targets. This can be administered as up-front investment subsidies, or ongoing operational support in the form of feed-in tariffs and fuel tax exemptions. Such funding could be sourced from the proceeds of EU ETS allowance sales.
- **Interconnection measures.** It is necessary to provide CHP developers with more clear and consistent rules and regulations for connecting to the electricity network – and with sufficient incentives for exporting electricity onto the grid. This has traditionally held back development of CHP at industrial and commercial sites.
- **Recognition of CHP in supporting climate change mitigation and emissions trading.** Emissions trading places a cap on greenhouse gas emissions allowances at the national level, and introduces a price for carbon emissions. The design of such systems should be such that CHP should benefit from the value of carbon saved. The current EU system does not achieve this.
- **Local heat planning.** Better heat planning can support the identification of suitable and stable heat loads for CHP, and the development of links to a heat supply at the local level. DH infrastructure can create the necessary network to link heat supply and demand – optimising energy supply in a highly efficient way through CHP.

4 Waste Heat Recovery

TABLE 14: SUMMARY OF POTENTIAL AND BENEFITS OF WASTE HEAT RECOVERY (WHR) IN KEY MARKETS

	France	Poland	UK
2020 benefits	▶ **0.7 Mt of CO_2 saved / yr** ▶ 9.5 TWh of primary energy savings	▶ **2 Mt of CO_2 saved / yr** ▶ 9.4 TWh of primary energy savings	▶ **2.4 Mt of CO_2 saved / yr** ▶ 11.3 TWh of primary energy savings
Options	▶ WHR from baseload reciprocating gas engines and larger gas turbines used in natural gas compression stations: **CO_2 saving: 1.1 Mt CO_2 across three markets** ▶ WHR from non-residential biomass boilers: **CO_2 saving: 2.4 Mt CO_2 across three markets** ▶ WHR from industrial processes: **CO_2 saving: 1.6 Mt CO_2 across three markets**		
Barriers	▶ **Lack of awareness** of waste heat recovery – not recognised by policy ▶ **Economics** – paybacks slightly too long for some applications ▶ **Uncertainty of heat supply** – needs to be continuous for waste heat recovery to work		
Recommend-ations	The key recommendation for waste heat recovery technology is simply for policy makers to recognise the energy and carbon savings that WHR offers and to ensure that appropriate incentives include it.		

Source: Delta Energy & Environment

4.1 Waste Heat Recovery Today

Waste heat from various processes can be captured and reused for useful heating or for generating mechanical or electrical work. We focus here on the opportunity to generate electricity from waste heat in applications where there is little or no local need for extra heat. The 3 main applications that we cover are:

1. Reciprocating gas engines and gas turbines that do not already recover waste heat
2. Waste heat recovery from industrial processes
3. Waste heat recovery from biomass boilers

There are other applications being trialled for waste heat recovery, most notably geothermal and solar thermal, however evidence to date suggests that these applications are generally not economic so will not be included in this analysis.

Generating power from waste heat typically involves using the waste heat to create mechanical energy that drives an electric generator. In a waste heat-to-power scheme, the waste heat is converted into electricity that can be either used onsite or sold to the grid, delivering direct energy savings and associated carbon emission reductions.

The efficiency of power generation is heavily dependent on the temperature of the waste heat source. The lower the quality of heat, the less efficiently it can be converted into electricity. In general, power generation from waste heat has been limited to only medium to high temperature waste heat sources, converted to power in traditional steam cycle turbines. However, advances in alternate power cycles, in particular the Organic Rankine Cycle (ORC), have improved the feasibility of generation at low temperatures. While the maximum efficiency of electricity generation at these temperatures is lower, these systems can still be economical in recovering large quantities of energy from waste heat. The table below summarises these two most common power generation technologies.

TABLE 15: THE MOST COMMON WHR TECHNOLOGIES FOR POWER GENERATION

Technology	Temperature range	Typical source of waste heat	Efficiency
Traditional steam cycle	Greater than 350°C	Exhaust from: ▶ Incinerators ▶ Furnaces	25 – 40% Average assumed 32.5%
Organic Rankine Cycle (ORC)	As low as 90°C	▶ Gas turbine exhaust ▶ Reciprocating engine exhaust ▶ Boiler exhaust ▶ Heated water ▶ Cement kilns	7 – 19% Average assumed ~ 13%

Source: Conversations with various WHR technology manufacturers

4.2 Current status of WHR activity in France, Poland and the UK

The current level of WHR activity in the three markets is very low – only a handful of projects go ahead each year. However, across all markets, WHR may be on the cusp of being economically attractive, with payback times usually of 3.5 to 7 years (based on offsetting electricity on an industrial tariff), just slightly too long to be prioritised by the customers in question.

None of the markets have policies that specifically recognise WHR:

- France has a system of White Certificates in place to promote energy efficiency in the industrial sector, but only a few measures are rewarded and power generation from WHR is not among them. Policy support for electricity from landfill gas actually disincentivises WHR – if power conversion from landfill is maintained at 85%, then a tax credit is awarded at a level of €7 per tonne of landfill converted. Adding WHR would push conversion above this threshold and the tax credit would be lost.
- Poland's Certificates of Origin system (supporting energy from renewable and low carbon sources such as biomass, biogas and CHP) does not explicitly recognise WHR. However there are a number of industrial customers paying very high electricity rates, therefore a handful of WHR projects have gone ahead based on good payback times alone (less than 4 years).
- The UK has several policies that could potentially reward electricity from WHR, but as yet do not. Electricity generated from biomass and biogas is eligible to receive Renewables Obligation Certificates (ROCs) – tradable certificates given for each MWh of electricity produced. Heat produced from biomass and biogas is to be rewarded by the Renewable Heat Incentive (RHI) from July 2011.

4.3 Key mechanisms through which WHR can deliver energy and CO_2 savings

WHR from baseload operation reciprocating engines and gas turbines

According to GE, there are more than 130,000 gas and diesel reciprocating engines (1 MW+) worldwide. About 30,000 units are running continuously, and over half of these are in applications with no onsite use for waste heat, such as landfills, waste water treatment and grid support. This application presents a considerable opportunity for the conversion of this waste heat into power. However as there is a lack of robust data available in Europe on the current and future installed capacity of engines suitable for waste heat recovery, this application will not be quantified in this analysis.

Another clear opportunity for waste heat recovery is from gas turbines in natural gas compressor stations. Natural gas pipeline networks rely on compressor stations to maintain a continuous flow of gas between supply areas and delivery to customers. Compressor stations are usually situated between 50 to 150 miles apart along the length of a pipeline system, and are typically designed to operate on an unattended and non-stop basis. These turbines are usually simple cycle, around 25 to 30 MW in capacity and generally do not recover the waste heat.

Based on GE Energy guidance, we have assumed in our analysis that for every MW of gas engine or gas turbine capacity, 100 kW of power can be recovered from the waste heat (assuming ORC technology is used)[3].

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[3] Source: GE Energy

Industrial processes

According to the US Department of Energy (DOE), as much as 20% to 50% of industrial energy consumption is ultimately discharged as waste heat. Much of this waste heat (around two thirds) is of too poor a quality to enable waste heat recovery, but a US study from the DOE[4] indicates that a potential 190 – 200 TWh of waste heat could be captured from the 'useful waste heat' for electricity generation. This equates to 2.6% of the final energy consumption by US industry.

Unlike the US, however, research on the potential for waste heat recovery in Europe, and data on the amount of industrial waste heat is simply not available. The proportion of industrial energy consumption in Europe lost as waste heat may be lower than the US in some EU member states but likely to be higher in others. In the absence of European data (we recommend new research into this area) we therefore apply the same factor for the three focus countries to determine the potential waste heat available for conversion to electricity.

The most energy intensive industries identified, with the greatest potential for waste heat recovery, include:

- Cement
- Iron and steel
- Glass

Waste heat from these industries is generally categorised as in Table 16.

TABLE 16. QUALITY OF WASTE HEAT FROM INDUSTRY

The majority of waste heat from industry is low grade, at temperatures <230 C.

Heat quality	Temperature	Typical sources	Suitable WHR technologies for electricity generation
High grade	> 650 C	Coke ovens Metals furnaces Glass furnaces Incinerators	Steam turbines
Medium grade	230 – 650 C	Cement kilns Exhaust gases Drying ovens	Steam turbines Organic Rankine cycle
Low grade	< 230 C	Exhaust gases Cooling water from furnaces, compressors Steam process condensate	Organic Rankine cycle

Source: BCS, Incorporated, 2008

The DOE found that around 60% of the useful industrial waste heat is low grade for which Organic Rankine Cycles can be implemented. A further 30% is typically medium grade heat, with only 10% being high grade. Assuming that half the medium grade heat is suitable for steam turbine based WHR, this limits the total amount of industrial waste heat for which steam turbine waste heat recovery is suitable to around 25%.

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[4] Source: BCS, Incorporated, Waste Heat Recovery: Technology and Opportunities in US Industry, 2008

Biomass boilers

Biomass heating plays a vital role in the 2020 renewable energy strategies of the three focus markets. Biomass boilers are typically 60% to 80% efficient, depending largely on load factor. This implies that 20% to 40% of the fuel input to these boilers is lost as waste heat to the atmosphere, a prime opportunity for waste heat recovery. Boiler exhaust is low grade heat so the ORC technology is most suitable.

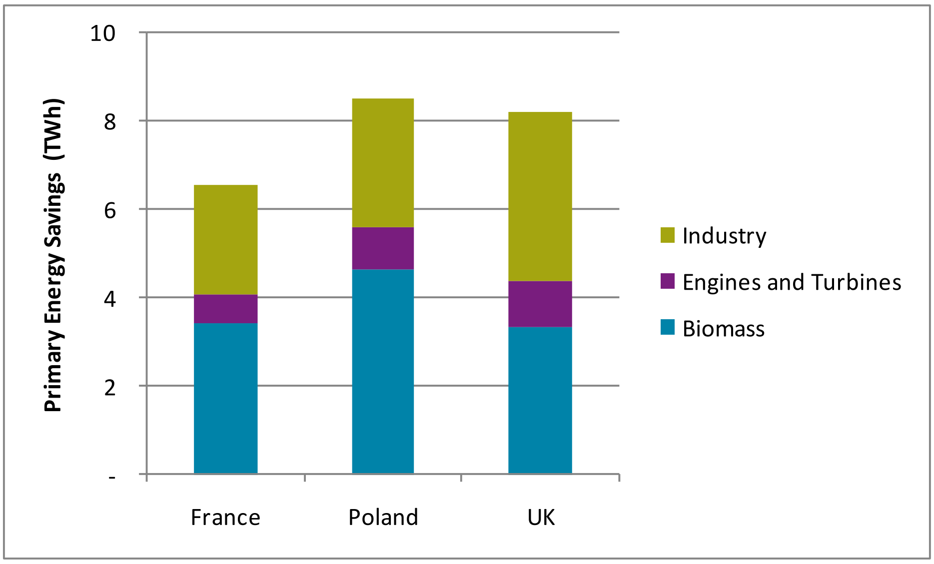
Using data from the national renewable strategies, we have assessed the opportunity to recover the waste heat from non-domestic biomass boilers, not including heat from biomass CHP. The assumptions we make for the analysis are in **Annex 4**.

4.4 Benefits of WHR deployment

All assumptions used in the calculation of the energy and CO_2 benefits of WHR are described in **Annex 4**.

Figure 21 describes the primary energy savings potential from widescale WHR deployment in the three focus markets based on the three technical options we have described.

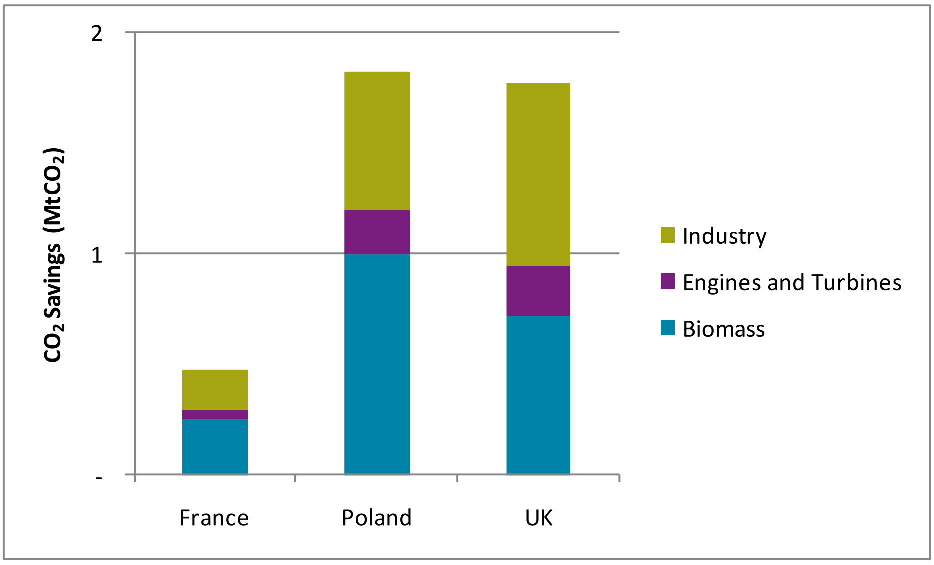
FIGURE 21: PRIMARY ENERGY SAVINGS FROM DEPLOYMENT OF WHR, 2020



Source: Delta Energy & Environment, 2011

Figure 22 illustrates how these primary energy savings translate into CO_2 emissions reduction. The assumptions we use for these calculations (for example the carbon intensity of the displaced electricity) are the same as those used for the CHP analysis.

FIGURE 22: CO_2 SAVINGS FROM DEPLOYMENT OF WHR, 2020



Source: Delta Energy & Environment, 2011

4.5 Barriers:

The main barriers to the uptake of waste heat recovery that we have identified are:

- Lack of awareness of WHR. Unlike in some parts of the US, WHR technology is not recognised by policy makers in Europe as a source of carbon free energy, and therefore is not directly incentivised or supported by policy.
- Economics. Paybacks on WHR technology usually range from 3.5 – 7 yrs or more, too long for many applications – particularly in industry. Investment in this technology is made more challenging by the capital constraints and small profit margins in some industries.

4.6 Recommendations

The key recommendation for waste heat recovery technology is for policy makers to increasingly recognise the energy and carbon savings that WHR offers and to ensure that appropriate incentives include it.

5 Smart Grid

TABLE 17: SUMMARY OF POTENTIAL AND BENEFITS OF SMART GRID IN KEY MARKETS

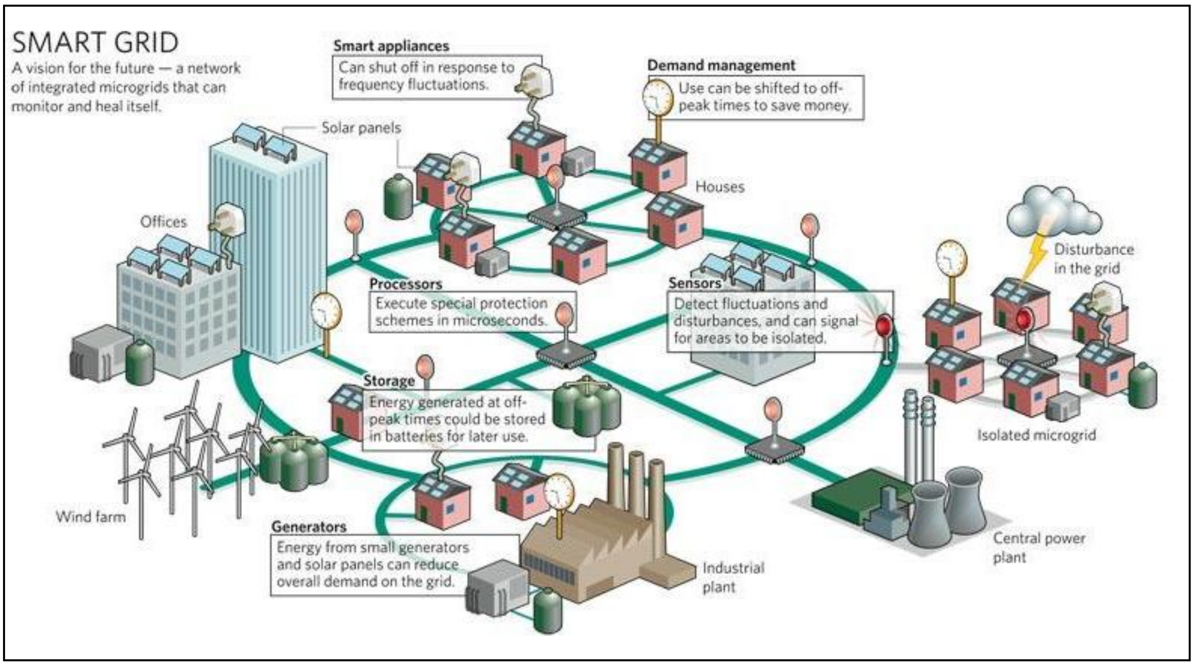
	France	Poland	UK
2020 benefits	▶ **4 Mt of CO_2 saved / yr** ▶ 49 TWh of primary energy savings	▶ **7 Mt of CO_2 saved / yr** ▶ 30 TWh of primary energy savings	▶ **13 Mt of CO_2 saved / yr** ▶ 60 TWh primary energy savings
Options	▶ Continuous diagnostics of energy consuming equipment in commercial and residential buildings: **CO_2 saving: 7 Mt CO_2 across three markets** ▶ Improved operational efficiency of the T&D system (reduced losses): **CO_2 saving: 7 Mt CO_2 across three markets** ▶ Smart demand - time-shifting of end-use electricity consumption through technologies enabled by the Smart Grid: **CO_2 saving: 1 Mt CO_2 across three markets** ▶ Influencing customer behaviour to reduce energy consumption through feedback: **CO_2 saving: 9 Mt CO_2 across three markets**		
Barriers	▶ Lack of clear national frameworks for Smart Grid among the member states ▶ Difficult to justify business case for investment in Smart Grid assets ▶ Regulatory risk in investment – potential for stranded assets if regulation changes e.g. around standards or minimum functionality requirements ▶ Unbundling can create issues around e.g. who owns the smart meter		
Recommend-ations	▶ Ensure sufficient incentive for investment ▶ Prioritise customer awareness of the benefits of the Smart Grid ▶ Develop an EU-level framework for Smart Grid development, with particular emphasis on: ○ Standardisation of smart grid technologies and communications protocols ○ Security and data protection ○ Minimum functionalities of Smart Grid hardware and software		

Source: Delta Energy & Environment

5.1 The Smart Grid in Europe today

There are many definitions of the widely used term, Smart Grid. The European Technology Platform (ETP), SmartGrids[5], defines it as follows: electricity networks **that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies**. The figure below provides an illustration of how the various users can be inter-linked.

FIGURE 23: THE SMART GRID



Source: Data Centre Pulse, 2011

The Smart Grid can also deliver energy efficiency benefits. Our approach to understanding this potential for energy and carbon emissions savings is, however, greatly limited to the extent that it is still very much in the planning and demonstration phase in Europe, and the potential benefits have not yet been assessed in any detail. We have therefore applied high level results, data and analyses from elsewhere, largely North America, to the European electricity system. A key element of our assessment is the smart meter: not highlighted in the diagram above, but integral to many of the energy benefits that we review.

We have also found that the Smart Grid opportunity receives significant attention at the EU-level, but so far this has not been fed down well to the national level – there appears to be a distinct lack of proper national frameworks for Smart Grid development in many member states. The following section summarises some relevant national activity.

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[5] http://www.smartgrids.eu/

5.2 Current status of Smart Grid activity in France, Poland and the UK

TABLE 18: SUMMARY OF SMART GRID ACTIVITY IN FRANCE, POLAND AND THE UK

Market	Details
France – developing a national framework; ahead of Poland, behind the UK.	▶ Developing a national framework for Smart Grid deployment, but this is not as advanced in its development as the UK. The French Smart Grid Roadmap sees a strong role for demand flexibility and electricity storage. ▶ In September 2010, the French government issued a decree that 95% of its smart meters must be deployed by year end 2016, well ahead of the European Union's mandate of 80% deployment by 2020. The French decree says all new meters deployed from 2012 onward must be smart meters and that daily data collection is required.
Poland – no clear national framework; only a focus on smart metering.	▶ Poland will begin to pay for its EU ETS emission allowances from 2016 onwards, at which point it is expected that electricity prices will rise sharply. Therefore, the regulator is keen to implement tools that enable customers to lower consumption. This includes a roll out of smart meters, although this is more or less the extent of smart grid plans so far. ▶ In late 2010, Poland's National Fund for Environmental Protection and Water Management announced a new €138m programme to fund feasibility studies, upgrading infrastructure and improving the energy efficiency of distribution networks. This fund is open for all DSOs to bid for, but they have to demonstrate an 8% energy saving to do so. There are few bids so far.
The UK – one of the leaders in developing a national Smart Grid Programme.	▶ The energy regulator, Ofgem, recognises the need for major investment in infrastructure. Ofgem has stated: "*We estimate that around £32 billion will have to be spent on pipes and wires over the next ten years to meet the challenging needs of energy producers and consumers as we decarbonise the energy sector*". ▶ The introduction of the Low Carbon Networks (LCN) Fund, with a budget of £500 million over 5 years, is a major measure to incentivise innovation in distribution networks, including Smart Grid initiatives. The LCN Fund has two major parts, one of which requires Ofgem to hold an annual competition to enable a small number of significant scale projects to receive funding.

Source: Delta Energy & Environment

5.3 Key mechanisms through which Smart Grids can deliver energy and CO_2 savings

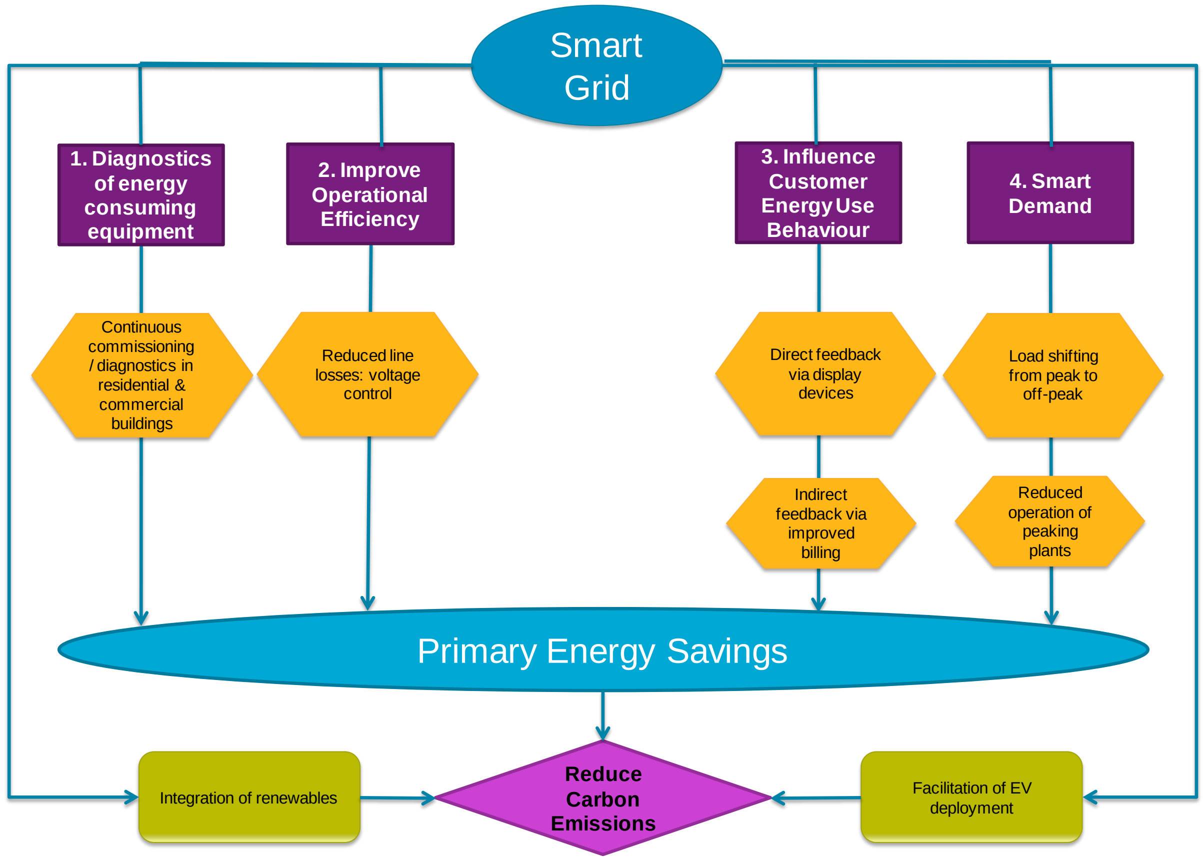
In identifying the energy and carbon savings benefits, we have considered the following Smart Grid mechanisms:

1. Continuous diagnostics of residential and commercial buildings
2. Improved operational efficiency
3. Changing customer energy use behaviour through direct feedback.
4. Smart demand

In addition, Smart Grid can facilitate greater integration of renewable power generation and the deployment of electric vehicles (EVs). These both result in CO_2 savings (discussed further on page 45).

These are all highlighted in the figure below.

FIGURE 24: SELECTED SMART GRID DEVELOPMENTS THAT CAN DELIVER ENERGY AND CARBON SAVINGS



Source: Adapted from EPRI (2008) and Pacific Northwest National Laboratory (2010)

Below, we summarise the assumptions we have made in identifying the benefits that these mechanisms can deliver.

Our sources and assumptions

We have aimed to assess the absolute benefits to be derived from wide scale Smart Grid deployment, rather than the marginal benefits compared to a business-as-usual scenario, which is near-impossible to identify given the lack of clarity over future national plans.

The sources that we have used to provide the necessary data and assumptions are summarised in the table below.

TABLE 19: SELECTED STUDIES THAT HAVE QUANTIFIED THE BENEFITS OF SMART GRID DEPLOYMENT

Study	Geographical coverage	Analysed benefits from	Energy savings 2020 (TWh)	CO_2 savings 2020 ($MtCO_2$)	Jobs
SMART 2020: Enabling the low carbon economy in the information age **The Climate Group, Global, 2008**	Global	▸ Integration of renewable energy ▸ Reduction in network T&D losses ▸ Demand management ▸ Reduce consumption through user information ▸ Intelligent load dispatch	1,540	2,030	NA
The Smart Grid: An Estimation of the Energy and CO_2 Benefits **Pacific Northwest National Laboratory (PNNL), US, 2010**	US	▸ Diagnostics of energy consuming equipment ▸ Consumer feedback ▸ Load shifting ▸ Integration of EVs ▸ Integration of renewables ▸ Joint marketing of energy efficiency and demand response ▸ Measurement and verification of energy efficiency programmes ▸ Reduced network T&D losses	467 – 606	277 - 359	NA

The Green Grid: **Energy Savings and Carbon Emissions Reductions Enabled** **by a Smart Grid** **EPRI, US, 2008**	US	▶ Diagnostics of energy consuming equipment ▶ Consumer feedback ▶ Load shifting ▶ Integration of EVs ▶ Integration of renewables ▶ Reduced network T&D losses ▶ Accelerated deployment of energy efficiency programmes	56-203	60 - 211	NA
The U.S. Smart Grid Revolution **KEMA's Perspectives for Job Creation** **KEMA, US, 2009**	US	Discussed on page 47	NA	NA	280,000 (deployment period of 3 years) 140,000 (steady state after deployment)
The IEA Smart Grids Roadmap **IEA, Global, 2011**	Global	▶ Peak load management ▶ Diagnostics of energy consuming equipment ▶ Reduced network T&D losses ▶ Consumer feedback ▶ Accelerated deployment of energy efficiency programmes ▶ Integration of EVs ▶ Integration of renewables	NA	Global: 800-1,100 by 2030 Europe: 70-90 by 2030	NA

Source: Delta Energy & Environment

Our assessments of the various Smart Grid mechanisms that we have reviewed are given below.

Continuous diagnostics in residential and small / medium commercial buildings

Heating, cooling and energy management systems in buildings degrade over time, leading to steadily increasing energy consumption which customers are frequently unaware of. The Smart Grid can enable these problems to be detected early by providing diagnostic services in residential and small / medium commercial buildings through automated real-time sensing and communication.

Examples of diagnostic checks that the Smart Grid can provide include:

- The efficiency of refrigerant cycles in heat pumps and air conditioners fall over time. The Smart Grid can detect declining efficiencies long before any equipment failure makes them obvious. Heat pumps that are providing unusual amounts of back-up electrical resistance heating (expensive and highly inefficient) can also be quickly detected.
- Economisers in building ventilation systems can save large amounts of energy as they provide ‘free cooling’ from outside air. They are, however, notorious for failing. When they do so, they can remain open all the time. The Smart Grid can enable continuous monitoring and optimising of the economiser’s position.
- A ‘smart’ HVAC (heating, ventilating and air conditioning) system can reduce energy consumption by around 10% by adjusting thermostats.

PNNL has estimated that the following reductions in electricity consumption are achievable through implementation of Smart Grid technologies:

- 15% in the residential sector for electricity serving heat pumps and air conditioners
- 20% in small / medium commercial buildings for HVAC and lighting.

Improvements in transmission and distribution (T&D) network operational efficiency

The Smart Grid can enable real-time monitoring and adjustment of some of the important operating parameters of the T&D network. Of particular concern is the system voltage. End-use energy consumption has been shown to drop when the electric service voltage is reduced. A strategy known as *conservation voltage reduction (CVR)* works on the principle that the energy consumed by certain end-use loads such as incandescent lights and some electronics is reduced as the voltage is decreased.

Conversely, losses in the distribution system tend to increase as the voltage drops, and as motors and other constant power loads draw more current to compensate. In the US, losses usually average around 5% and increase to 8% or more during peak loads when voltage drops and current increases[6]. A Smart Grid can provide the measurement and communication functions to continually optimise trade-offs in system voltage and energy use by precisely controlling the voltage within acceptable limits. This optimisation process, which includes CVR, is known as *advanced voltage control*.

CVR: a comprehensive study[7] of CVR involved 31 feeders at 10 different substations and 11 utilities in the Pacific Northwest in the US. It showed that a 1% change in the distribution line voltage provided a 0.25% to 1.3% change in energy consumption, and that voltages could be reduced from 1% to 3.5%.

Advanced voltage control: PNNL estimated that it is possible to reduce existing consumption of electricity by approximately 1% with relatively little investment. Deploying full advanced voltage control could potentially increase this from 3% to 4%.

For the purposes of this assessment, we have assumed an average of 2% reduction of electricity supplied to the grid for the three countries through the implementation of these mechanisms.

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[6] We recognise that the general condition of European electricity networks is higher than that of networks in the US.

[7] http://www.comedamifuture.com/Resources/DEI%20Final%20Report%201207.pdf

Smart demand

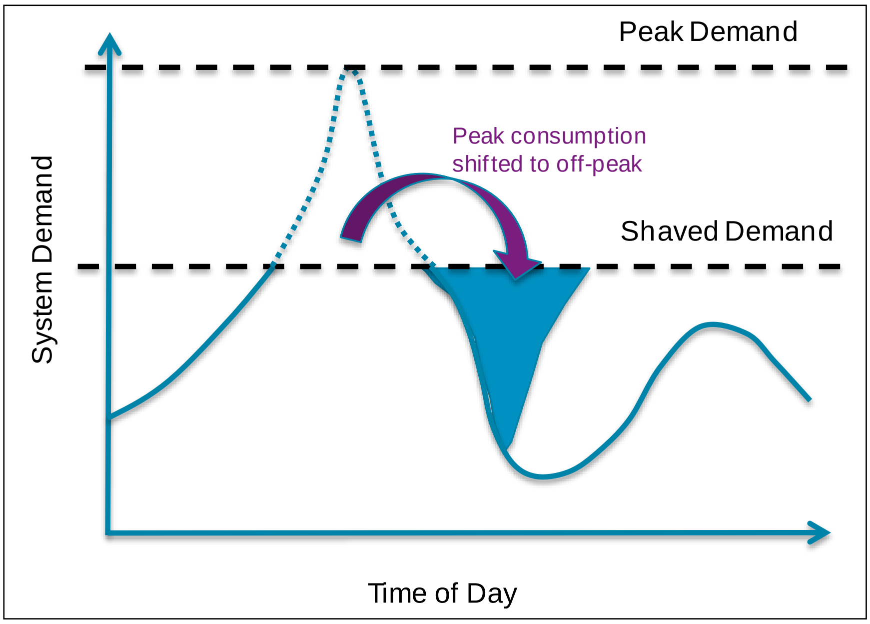
The term 'smart demand' refers to the time-shifting of end-use electricity consumption through technologies enabled by the Smart Grid. For example:

- Incentivising customers to run their energy consumption appliances during the night through time-of-use tariffs delivered through smart meters. The appliances could be controlled automatically by a Home Energy Management (HEM) system.
- In the commercial or industrial sectors, Information and Communications Technology (ICT) solutions can be integrated to receive signals from the network operator that the local network is congested, and the customer will be rewarded if they reduce or cut non-critical loads.

The benefits of load-shifting are primarily:

- To shave system 'peaks' – this reduces the need for peaking plants which are often less efficient and/or use more polluting fuels, to run; it can also enable delay or prevention of the need for investment in new network capacity.
- To fill system 'valleys' – this can help increase and optimise the operation of lower carbon baseload plant (including nuclear and some renewable plant).

FIGURE 25: ILLUSTRATIVE EXAMPLE OF LOAD SHIFTING



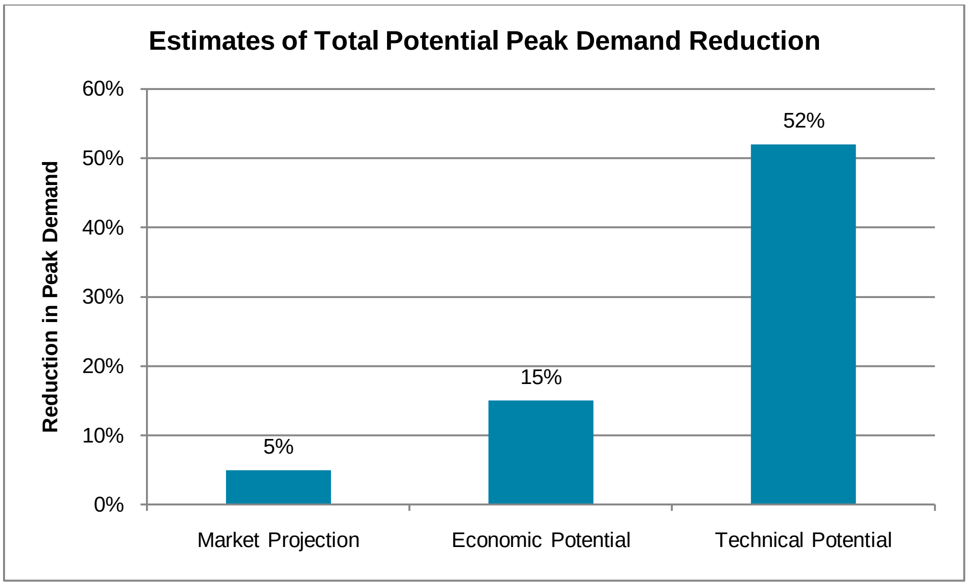
Source: Delta Energy & Environment

The Smart Grid can facilitate shifting load from peak periods to off-peak periods through various means, including *demand response* (either direct control of loads or, more commonly, using dynamic or time-of-use tariffs to incentivise off-peak consumption), *distributed generation (DG)* and *electricity storage*.

The energy and carbon emissions savings that will result from load shifting will depend on the mix of baseload, intermediate and peak generating resources being used at a particular time. However, the highly dynamic nature of power plant dispatch options makes the assessment of these energy and carbon savings highly complex. To do so fully requires detailed modelling of wholesale market operation, generation plant merit orders, etc.

We have therefore derived our assumptions on peak demand reduction from the Brattle Group[8]. Its analysis concluded that demand response across all sectors (through the use of time-of-use tariffs) can shift 5% of the system peak to off-peak times[9]. This estimate is based on the assumption that 43% of customers in each sector (residential, commercial and industrial) implement a cost-effective combination of demand response enabling technologies (such as smart meters, load controlling devices in industrial and commercial buildings, home energy management systems, or controllable heat pumps or air conditioners).

FIGURE 26: THE BRATTLE GROUP ESTIMATES A 5% REDUCTION IN SYSTEM PEAK DEMAND FROM DEPLOYMENT OF THE SMART GRID



Source: The Brattle Group, 2007

The carbon savings that will arise from shifting 5% of peak demand will depend on the difference in the carbon intensity of the generation meeting peak demand, and that of the off-peak generation:

- This is most relevant in France in 2020, where we assume that peaking generation will be a mix of open cycle and combined cycle gas turbines, and off-peak electricity will be largely nuclear and renewables.
- In Poland and the UK in 2020, there is not likely to be such a significant difference in the carbon intensity of peak and off-peak generation, so we have not assessed these two countries for this mechanism.

In respect of energy savings, results from Pacific Gas and Electric's (PG&E, USA) Critical Peak Pricing (CPP) tariff programme show that for every kWe of peak demand reduction, 65 kWh of energy savings result. The results of this programme apply to commercial customers only, but for simplicity we assume (as EPRI has also done) that this assumption applies to residential and industrial customers too.

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[8] http://www.brattle.com/_documents/UploadLibrary/Upload578.pdf

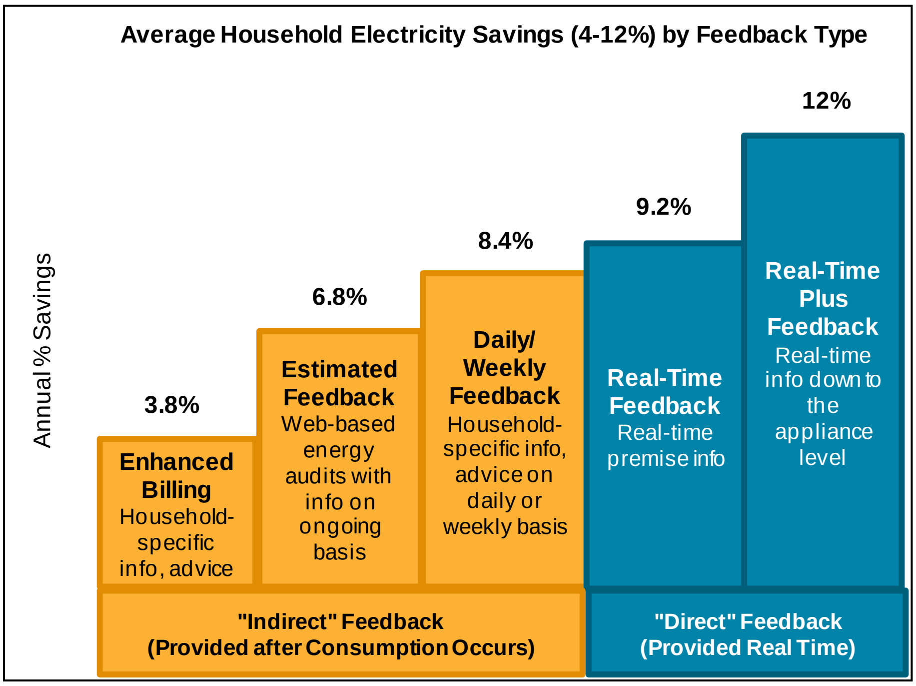
[9] For example, the system peak in the UK in 2020 is projected to be 68.5 GW. Shifting 5% of this peak for 500 hours (2 hours per working day, the assumption used in the analysis of each of the three markets) means that 1.7 TWh of electricity is generated by off-peak power plants, as opposed to peaking plants.

Customer behaviour

The Smart Grid can enable energy consumption feedback to be delivered to consumers in a range of ways, from more accurate billing (e.g. from data communicated by smart meters) to feedback down to the appliance level (through the most advanced HEM systems). There has been a general supposition that this causes consumers to manage and reduce their demand, but the direct impact of such feedback on consumption is subject to debate.

Figure 27 below was taken from a 2010 meta-analysis[10] of 36 separate studies on the effects of customer feedback on household electricity savings. The results vary between 4 and 12%, depending on the method and time of feedback.

FIGURE 27: THIS META-ANALYSIS SHOWS THAT UP TO 12% ENERGY SAVINGS ARE ACHIEVABLE IF REAL-TIME FEEDBACK AT THE APPLIANCE LEVEL IS PROVIDED



Source: Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities, American Council for an Energy-Efficiency Economy (ACEEE), US, 2010

Finally, for its 2008 study, EPRI assumed that consumer information and feedback systems resulted in electricity savings of:

- 5% for residential customers
- 2.5% for non-residential customers.

Based on the data from the sources above, the EPRI assumptions for residential customers appear to be solid, even conservative, and we have chosen these values as the basis of our assessment. As there is no available data for non-residential customers, we have assumed a more conservative value of 2%.

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[10] A meta-analysis combines the results of several independent studies that address a set of related research hypotheses

Enabling the wider penetration of electric vehicles (EVs) through smart charging

The replacement of petrol vehicles with electric vehicles will also result in primary energy savings and CO_2 emissions reduction. If EV charging times are managed through the Smart Grid, as they are likely to be in due course, it will be possible to enable ‘smart charging’ of EVs to take advantage of greater inflexible renewable and nuclear generation, and to manage the increased electricity demand in such a way as to minimise the need to build out additional generation or T&D networks.

The Smart Grid can facilitate increased penetration of renewables

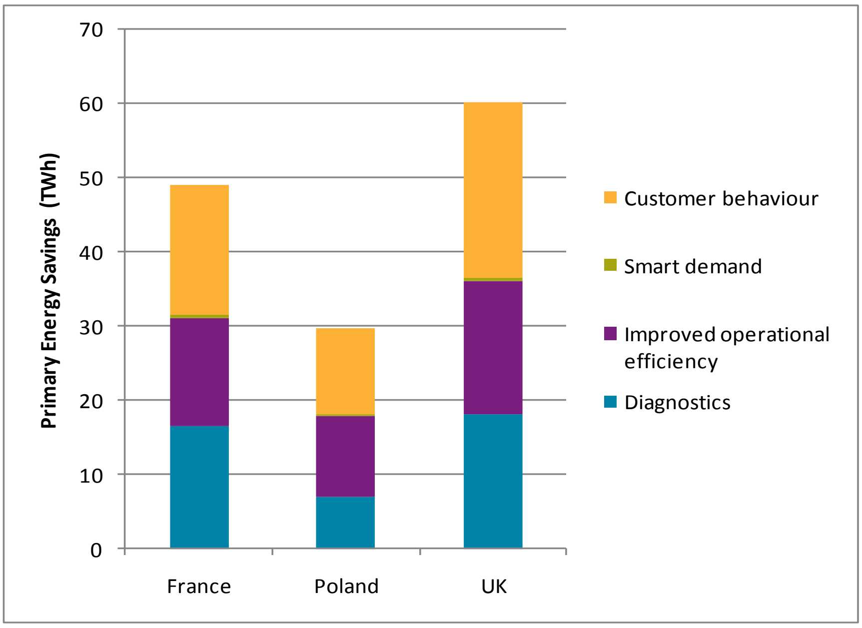
Increasing penetration of intermittent renewable generation increases the need for load following services, currently provided by fossil power plants. As we describe in Chapter 2, these plants are ramped up and down as renewable generation and final demand rise and fall, wasting fuel and increasing wear and tear on the plants. Smart Grid resources (for example demand response, distributed generation and electricity storage) can help to balance supply and demand more effectively.

5.4 Benefits of smart grid deployment

Our main assumptions used in the calculation of the energy and CO_2 benefits of the Smart Grid are described in **Annex 3**.

Figure 28 describes the primary energy savings potential from a widescale Smart Grid deployment in the three focus markets. There are considerable savings to be gained from all but smart demand, where the focus is on shifting the peak, not on actual energy savings.

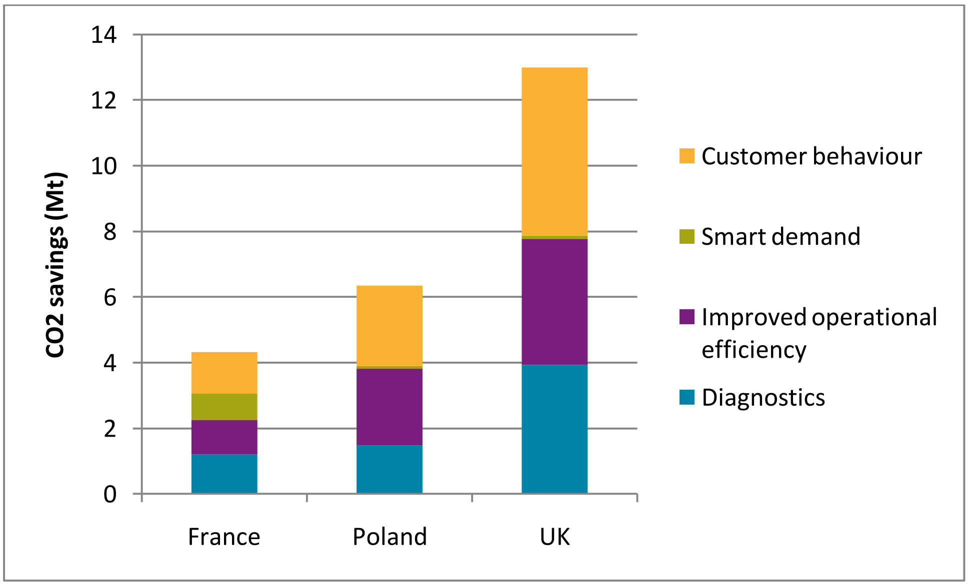
FIGURE 28: PRIMARY ENERGY SAVINGS FROM DEPLOYMENT OF SMART GRID, 2020



Source: Delta Energy & Environment, 2011

Figure 29 illustrates how these primary energy savings translate into CO_2 emissions reduction. The clearest opportunity is in the UK, where there is the potential to reduce CO_2 emissions by around 13 Mt CO_2 per annum by 2020.

FIGURE 29: CO_2 SAVINGS FROM DEPLOYMENT OF SMART GRID, 2020



Source: Delta Energy & Environment, 2011

Jobs benefits

There have been no studies into the potential job creation from a Smart Grid deployment in the UK, France or Poland, or in the EU. The most comprehensive study looking at this issue was undertaken by KEMA, again in the US, in 2009. Smart Grid jobs are created directly from the following categories:

1. Direct utility employees[11] – the net addition of new skills less the displacement of lower-skilled workers (e.g. meter readers).
2. Contractors – employed to accelerate installation and deployment of Smart Grid services.
3. Direct utility suppliers
    a. Meter vendors
    b. T&D automation device providers
    c. ICT product & service providers
    d. Software system providers & integrators.
4. There is also indirect job creation from, for example, the supply chain and EV providers.

Table 20 outlines the job creation potential from Smart Grid deployment in the three focus markets. The KEMA study uses the following assumptions:

- 1 Smart Grid project per 1 million smart meters deployed.
- An overall cost of €350 million per project, with labour costs comprising 30% of this.
- An average cost of around €50,000 per employee.

We have applied these parameters to the 3 focus markets based on our assumptions on smart meter deployment.

TABLE 20: NEW JOBS CREATED BY SMART GRID DEPLOYMENT, 2012 TO 2020

	France		Poland		UK	
	Deployment period (2012 to 2014)	Steady state period[12] (2015 to 2020)	Deployment period (2012 to 2014)	Steady state period (2015 to 2020)	Deployment period (2012 to 2014)	Steady state period (2015 to 2020)
Direct Utility Smart Grid	13,500	1,500	5,000	500	11,000	1,500
Transitioned (Lost) Utility Jobs	- 3,000	- 9,000	- 1,000	- 3,000	- 2,500	- 7,500
Contractors	5,500	500	2,000	200	4,500	500
Direct Utility Suppliers	33,000	25,000	12,000	9,000	27,000	21,000
Total Jobs excluding indirect	**49,000**	**18,000**	**18,000**	**6,700**	**40,000**	**15,500**

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[11] Direct utility employees are those with the new skills required to implement a Smart Grid, such as installers, IT and communications experts, project managers etc.

[12] Steady state jobs will persist beyond the Smart Grid deployment period as permanent, on-going and high-value positions.

We recognise that this does not, indeed cannot, represent a rigorous analysis of the Smart Grid job creation opportunity in Europe, but a high level and indicative view. In comparing the US with Europe for example:

- The staging of deployment of the projects will be different.
- The cost of labour in the three markets will vary widely, with Poland being lower than UK and France.
- In respect of domestic jobs created in the supply chain, the US has a stronger domestic industry servicing the sectors mentioned than in our three focus countries.

5.5 Barriers

The development of the Smart Grid in Europe appears to be a question of ‘when?’ and not ‘if’. But it appears as if Europe could be moving faster in this area and that other parts of the world may already be ahead. This might explain why much of the research that has been undertaken on the benefits of Smart Grid is from the US. Some of the member states in particular could perhaps ‘up their game’ in this area.

For example, we have found that

- There are large sums of money for Smart Grid being discussed at EU level, but in some member states there is only modest activity.
- Justifying the business case for investment in Smart Grid can be difficult. Traditionally, network assets have long lifetimes – often several decades – from which to earn revenue. Smart grid technologies have shorter lifetimes, as low as 5 - 10 years. In addition, a priority for network operators has traditionally been to limit risk and reduce costs rather than to innovate.
- The unbundling of Europe’s utilities is creating some challenges. For example, who should own the smart meter?
- There is the potential for regulatory risk. Utilities will want to avoid any risk of stranded assets, or having to install infrastructure more than once.
- In Poland, we have found that considerable emphasis is being placed on smart meter roll-out and very little to wider Smart Grid development linked, for example, to infrastructure renewal.

5.6 Recommendations

We propose the following options for measures that can be implemented by regulators and policymakers to deliver the potential that we have identified:

- Ensure that there is sufficient incentive for energy companies and others to invest in Smart Grid R&D and infrastructure development. This can include funding member state research into cost / benefit analyses, e.g. for smart meter deployment (there remains considerable uncertainty around the business case for smart meters (e.g. DONG Energy, in Denmark, is suspending its plans for full roll-out). It can also include allowing DSOs to gain a sufficient return on investment in Smart Grid initiatives.
- Ensure that energy suppliers and others prioritise customer communication throughout the transition – it is important that benefits accrue to customers since their engagement will be necessary for delivery of many of the key benefits.
- An EU-level framework will be needed to address some key elements of Smart Grid development, for example:
  - Standardisation of smart grid technologies and communications protocols
  - Security and data protection
  - Minimum functionalities of Smart Grid hardware and software.

6 Comparing supply-side with demand-side efficiency

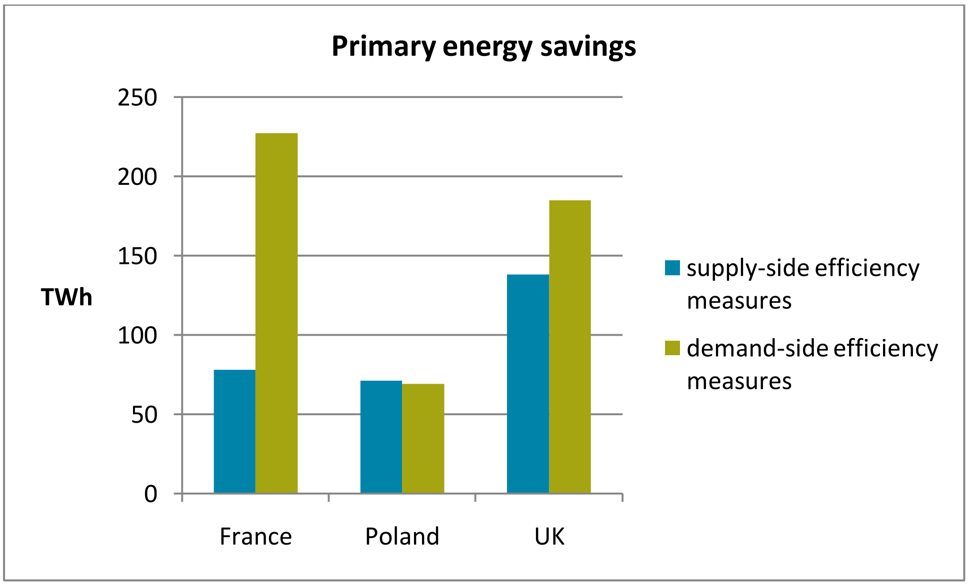
The high importance of cost-effective demand-side efficiency measures has been well recognised by the EU institutions and by many member states - most recently the EU Energy Efficiency Plan published in March 2011.

As part of our analysis, we have also compared the primary energy saving benefits of the supply side efficiency measures that we have assessed (there are other options that we have not assessed) with those of demand-side measures that the member states have identified over a similar time-frame in their 2007/08 National Energy Efficiency Plans (of the three, only the UK also stated its associated CO_2 savings).

Using European Commission energy statistics data from 2009, we have stripped transport measures out of the analysis to enable a fairer comparison, and have converted the demand-side efficiency potential into equivalent primary energy savings.

The comparisons are shown in the figure below.

FIGURE 30: ANNUAL PRIMARY ENERGY SAVINGS BY 2020



Source: Delta Energy & Environment, 2011

If we were to take a comprehensive range of supply-side measures into account, we believe that the benefits would exceed considerably those of demand-side measures in Poland and be similar in scale in the UK. The UK comparison is an interesting one: its demand-side efficiency potential is particularly high in part because its building stock is notoriously energy inefficient.

Technical Annex

Annex 1: Power Plant Efficiency

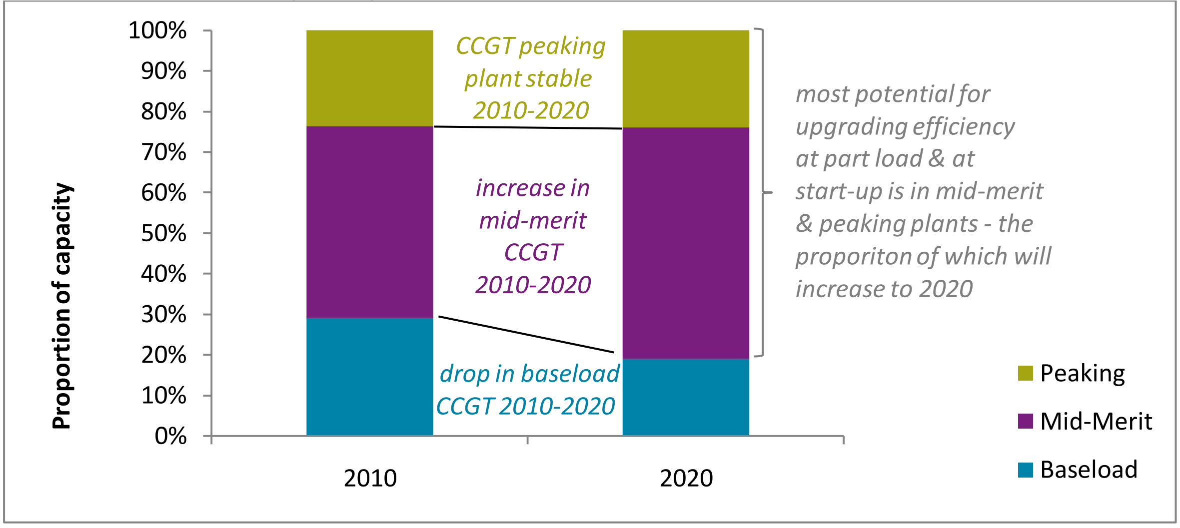
Assumptions on potential for efficiency improvements to 2020 UK CCGT fleet

- **Plants less than 12 years old**: Delta assumes no improvements would be made to these plants
- **Plants of 12-24 years**: 10% of the 2020 fleet will be between 12 and 18 years old, and 44% will be between 18 and 24 years old. Technology upgrades and implementation of advanced performance monitoring could yield benefits in the order of 2% - counter-acting the effects of degradation over time, and potentially raising the efficiency to close to the efficiency of a new plant built in 2020.
- **Plants over 24 years:** Delta assumes plants of over this age in 2020 are close to being decommissioned. The efficiency gains will be very limited as less investment is likely to be made in them.

NOTE: Technology upgrades – improving efficiency at part load & at start-up: Potential efficiency gains through these mechanisms are dependent on the way the plant is running. If the plant is in a peaking role, stopping and starting every day, efficiency gains in the order of 5% are possible. If the plant is baseload, efficiency gains through implementation of this technology will be minimal. Improving efficiency at part load will have an impact where plants are ramping up and down often between full and part load (mid-merit plants). The following graph shows the assumptions we use, based on UK National Grid information, about the proportion of CCGTs running as baseload, mid-merit and peaking plant in 2020. Based on Delta's conversations with industry experts, we have come to a view of how this proportion of baseload / mid-merit / peaking will change to 2020, with a reduction in baseload being taken up by an increase in the more cyclical plants.

FIGURE 31: ASSUMPTIONS ABOUT OPERATIONAL REGIMES OF UK CCGT PLANTS IN 2010 & 2020

There are no well-defined projections for the exact proportion of baseload / mid-merit / peaking plant in 2020, but based on conversations with our industry networks, Delta is of the view that baseload CCGT may reduce to <10%, while peaking plant may increase to 30-40% by 2020 – in response to the need to balance the growing nuclear baseload and intermittent renewables.



Source: 2010 - National Grid Winter Outlook 2010; 2020 projection – Delta Energy & Environment, 2011

Assumptions on generic efficiency gains & efficiency degradation over time in CCGT plants

TABLE 21: ASSUMPTIONS ON EFFICIENCY GAINS

Efficiency mechanism	Type of plant	Potential for improvements (max % efficiency gain)
Technology upgrades: overall efficiency	baseload	2.0%
	mid-merit	2.0%
	peaking	2.0%
Technology upgrades: efficiency at start up	baseload	0.05%
	mid-merit	0.5%
	peaking	3.0%
Technology upgrades: efficiency at part load	baseload	0.0%
	mid-merit	2.0%
	peaking	0.0%
Performance monitoring, & operation & maintenance practices	baseload	1.25%
	mid-merit	1.25%
	peaking	1.25%
Dispatch patterns	baseload	0%
	mid-merit	5%
	peaking	10%

Source: Delta conversations with E.On UK, ESB Ireland, GE Energy

TABLE 22: ASSUMPTIONS ON DEGRADATION OF CCGT PLANT EFFICIENCY OVER TIME

	Age of plant (yrs)				
Type of operation	**0**	**6**	**12**	**18**	**24**
Baseload	50.7%	50.2%	49.7%	49.2%	48.7%
Mid-merit	48.2%	47.7%	47.2%	46.7%	46.2%
Peaking	45.7%	45.2%	44.7%	44.2%	43.7%

Source: Delta conversations with E.On UK, ESB Ireland, GE Energy

Technology upgrades for CCGT plants

Cooling optimisation in CCGT plants: 0.5% heat rate improvement

Gas turbine combustion takes place at higher temperatures than the metal of the turbine can stand, so cooling mechanisms are required to avoid damage or melting. One mechanism to deal with this is through extracting air from the compressor to create a film of cool air around the turbine. This process can be optimised to maximise efficiency of the process:

- **Traditional cooling control systems** - these extract sufficient cooling air to meet a 'worst case scenario', so turbines are cooled more than necessary, resulting in reduced efficiency.
- **Cooling optimisation** - air used to cool components is used more efficiently (only as much as is necessary) through *active control of cooling flows* – a 'compressor ejector' modulates the airflow around the turbine, and reduces the amount of air the compressor needs - improving the process efficiency.

Reducing leakage in a gas turbine

Through more sophisticated control over the clearance between rotating and stationary parts within a gas turbine, leakage can be minimised and thus efficiency increased.

Automated performance monitoring

There are many packages on the market which deliver performance monitoring. The technology continually monitors the performance characteristics of key assets in the plant (e.g. boilers, water-steam cycle, cooling water cycle, auxiliary systems), comparing the effectiveness of current performance to an optimal performance based on a computer-based thermodynamic model of the power plant.

Implementation of such performance monitoring packages means that:

- The causes of reduced efficiency can be identified early.
- Operational practices can be adjusted (more informed decisions are made by the plant operator) to improve performance.
- Losses resulting from equipment degradation, downtime and emergency repairs can be prevented.
- Maintenance strategies can be optimised, avoiding reactive emergency maintenance & associated (un-planned) plant down-time which result in efficiency losses.

Annex 2: CHP

The assumptions used for modelling the CO_2 and energy savings from CHP are as follows:

- For all countries, we assume that the CHP displaces separate generation of electricity and heat as described below. We do not consider that the shares of CHP in the overall power generation market are high enough in any of the countries to require that new CHP displaces existing CHP plant.
- *Electricity displaced by new CHP*. We assume an average fossil carbon intensity of grid electricity. This excludes nuclear power and renewable energy sources. In practice, these are unlikely to be displaced by CHP. For example, existing nuclear power is usually fully depreciated and a low price generator, while renewables often benefits from obligations or feed-in tariff incentives that ensure dispatch[13]. To assess this average, we have assumed the following electricity fossil mixes for 2020:
    - France
        - Fossil generation – 54% natural gas, 43% coal, 3% oil.
        - 44.5% average efficiency of fossil fuel generation.
    - Poland
        - Fossil generation - 84% coal, 16% natural gas.
        - 40.0% average efficiency of fuel generation.
    - UK
        - Fossil generation – 63% natural gas, 37% coal.
        - 45.5% average efficiency of fuel generation.

- **Heat displaced by new CHP**. A CHP scheme is installed to meet a heating (and occasionally a cooling demand), either existing or new. An existing heat demand would otherwise be provided by boilers. Existing boilers have well-known characteristics and it is relatively straightforward to calculate avoided emissions. There are now very limited opportunities to increase the efficiency of new boilers. For France and the UK, we assume that the CHP displaces gas boilers. For Poland, because of the high use of coal in the country, we assume a 50/50 mix of gas and coal boilers are displaced.
- For building / DH CHP in 2020, we have modelled:
    - 1 MWe Gas engine CHP
    - Fulfils EU CHP directive definition of high efficiency cogeneration.
    - Electrical efficiency (LHV) 40%
    - 5500 hrs/yr operation
    - Heat / power ratio 1.29
    - 100% electricity used on-site

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[13] Other examples of this approach include:

1. The UK – “in practice, fossil fuel fired generation is reduced more quickly in response to falls in electricity demand. Renewable and especially nuclear generation tends to operate at maximum capacity as much as possible”. *Savings in carbon emissions resulting from the use of Combined Heat and Power, Energy Trends, UK Government, 2003.*
2. France - French electricity transmission operator RTE is supportive of using marginal grid factors for CHP and renewables (equivalent to average fossil) but that the issue should be addressed on a case by case basis.
3. Germany - For the purposes of voluntary CHP user calculations, the German government bases the methodology on the average grid mix, but also presents calculations based on the fossil-only part of the grid mix, when projecting the development of the power sector in the future.

- For industrial CHP - 2020, we have modelled
    - 50 MWe Gas turbine CHP (note: CCGT based CHP can also be applied at large industrial sites)
    - Fulfils EU CHP directive definition of high efficiency cogeneration.
    - Electrical efficiency (LHV) 39%
    - 8.200 hrs/yr operation
    - Heat / power ratio 1.11
    - 75% electricity used on-site
    - Displaces gas boiler (except Poland, displaces 50/50 mix coal/gas boilers)
- Average T&D losses – 2020
    - France 6.7%
    - Poland 8.7%
    - UK 7.7%
    - We assume a non-industrial CHP, connected at lower voltage, avoids a higher share of network losses than an industrial CHP, which is connected at higher voltage.
- **Share of new industrial & building DH / CHP.** We have assumed a ratio of around 2:1 of industrial: building & DH CHP. In general, the economic conditions are more favourable for industrial CHP based on their high load factors. DH projects tend to face high up front capital costs associated with the development of heat distribution infrastructure. All three countries have significant additional economic potential for industrial CHP development.

Annex 3: Smart Grid

TABLE 23: ASSUMPTIONS USED IN CALCULATION OF BENEFITS

	France	Poland	UK	Source
Average grid carbon contents in 2020 (gCO_2/kWh)	83	625	425	France: assumed same as today, Poland assumed slightly lower than today with more gas and renewables UK: CCC, 2008
Total electricity supplied to the grid in 2020 (GWh)	637,250	187,136	451,496	EU Commission, 2009
T&D losses in 2020	6.7%	8.7%	7.7%	Delta assumptions based on IEA data
Total fuel input to generation in 2020 (GWh)	728,959	546,037	889,127	EU Commission, 2009
Average conversion efficiency in 2020	87%	34%	51%	Calculated
1. Diagnostics				
Number of residential heat pumps in 2020	2,000,000	50,000	635,000	Delta, 2011
Number of residential air conditioners in 2020	3,754,311	93,905	4,270,398	DGTREN, 2008
Electricity consumption of heat pumps per home (kWh)	9,500	9,500	9,500	Delta, 2011
Electricity consumption of air conditioners per home (kWh)	5,000	3,500	3,000	Delta, 2011
Total electricity consumption in commercial buildings (GWh) 2020	150,900	39,200	109,900	Eurelectric, 2010
% share of HVAC and lighting in small/medium buildings	26%	26%	26%	PNNL, 2010
2. Smart demand				
Carbon intensity of peak (g CO_2 / kWh) in 2020	545	545	392	UK: Predominantly gas CCGT, with some distillate, pumped storage and oil. (National Grid, 2010). France assumed mix of gas CCGT and OCGT. Poland assumed equal mix of coal and oil.
Peak shifted (hours)	500	500	500	Estimated, 2 hours per working day, GE Energy, 2011
Peak Demand (GW) 2020	90.9	28.9	68.5	Eurelectric, 2010
3. Customer behaviour				
Total final electricity consumption by sector (TWh) in 2020				
Households	157.4	34.8	127.4	Eurelectric, 2010
Industry	171.6	54.5	127.1	Eurelectric, 2010
Services	150.9	39.2	109.9	Eurelectric, 2010

Source: Delta Energy & Environment

Annex 4: Waste Heat Recovery

Gas turbines used in natural gas compression stations

TABLE 24: ASSUMPTIONS USED IN CALCULATION OF WASTE HEAT RECOVERY POTENTIAL FROM GAS TURBINES IN NATURAL GAS COMPRESSOR STATIONS

	France	Poland	UK	Source
Turbines	25	14	23	GRTgaz, GAZ-SYSTEM, National Grid, GE Oil & Gas
Capacity (MW)	750	350	690	Average unit capacity 25 MWe: GE Oil & Gas
Running hours	8500	8500	8500	GE Oil & Gas
Gas turbine generation (TWh)	6.375	2.975	5.865	
Potential from ORC (TWh)	0.64	0.30	0.59	GE Energy

Source: Delta Energy & Environment

Industrial processes

TABLE 25: ASSUMPTIONS USED IN CALCULATION OF WASTE HEAT RECOVERY POTENTIAL FROM INDUSTRIAL PROCESSES

	France	Poland	UK	Source
Final energy consumption by industry (TWh) in 2020	403.4	218.9	385.7	EU Energy Trends to 2030, 2009
Proportion of industrial energy demand from which suitable waste heat is produced (%)	33.6	33.6	33.6	BCS, Incorporated, Waste Heat Recovery: Technology and Opportunities in US Industry, 2008
Energy consumption on which WHR is possible (TWh)	135.6	73.6	129.6	
Proportion of energy demand that result in useful waste heat (%)	7.9%	7.9%	7.9%	BCS, Incorporated, 2008
Waste heat potential (TWh)	10.7	5.8	10.2	
Proportion of waste heat by grade	▶ Low grade = 60% ▶ Medium grade = 30% ▶ High grade = 10%			BCS, Incorporated, 2008
Proportion of waste heat used by ORC (%)	75	75	75	BCS, Incorporated, 2008 Recycled Energy Development, 2011
ORC efficiency (%)	13	13	13	Numerous manufacturers, 2011
Proportion of waste heat used by steam turbines (%)	25	25	25	BCS, Incorporated, 2008 Recycled Energy Development, 2011
Steam turbine efficiency (%)	32.5	32.5	32.5	Numerous sources, 2011 Recycled Energy Development, 2011
Electricity from WHR ORC (TWh)	1.04	0.56	0.99	
Electricity from WHR ST (TWh)	0.87	0.47	0.83	

Source: Delta Energy & Environment

Biomass boilers

TABLE 26: ASSUMPTIONS USED IN CALCULATION OF WASTE HEAT RECOVERY POTENTIAL FROM BIOMASS BOILERS

	France	Poland	UK	Source
Biomass heat suitable[14] for WHR (GWh)	60,476	31,300	33,762	2020 Renewable Action Strategies for each Member State.
Running hours	5,000	5,000	5,000	Intermediate load based on approximated annual heating hours.
Capacity suitable for WHR (GWth)	12.10	6.26	6.75	
Biomass boiler efficiency	75%	75%	75%	Biomass Energy Centre (UK), 2011
Waste heat potential (GWth)	5.18	2.68	2.89	
Electricity potential from ORC WHR (GWe) based on electrical efficiency of 13%.	0.67	0.35	0.38	

Source: Delta Energy & Environment

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[14] Suitable biomass heat refers to that from larger (non-domestic) boilers, and not already CHP

7 Acknowledgements

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