E.ON Energy Research Center
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FCN Working Paper No. 5/2009

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Revised March 2010

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The benefit of regional diversification of cogeneration investments in Europe: A mean-variance portfolio analysis

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November 2009 (revised March 2010)

Abstract

The EU Directive 2004/8/EC, concerning the promotion of cogeneration, established principles on how EU member states can support combined heat and power generation (CHP). Up to now, the implementation of these principles into national law has not been uniform, and has led to the adoption of different promotion schemes for CHP across the EU member states. In this paper, we first give an overview of the promotion schemes for CHP in various European countries. In a next step, we take two standard CHP technologies, combined-cycle gas turbines (CCGT-CHP) and engine-CHP, and apply exemplarily four selected support mechanisms used in the four largest European energy markets: feed-in tariffs in Germany; energy efficiency certificates in Italy; benefits through tax reduction in the UK; and purchase obligations for power from CHP generation in France. For contracting companies, it could be of interest to diversify their investment in new CHP facilities regionally over several countries in order to reduce country and regulatory risk. By applying Mean-Variance Portfolio (MVP) theory, we derive characteristic return-risk profiles of the selected CHP technologies in different countries. The results show that the returns on CHP investments differ significantly depending on the country, the support scheme, and the selected technology studied. While a regional diversification of investments in CCGT-CHP does not contribute to reducing portfolio risks, a diversification of investments in engine-CHP can decrease the risk exposure.

Key words: Combined heat and power, CHP promotion scheme, Portfolio optimization

JEL Classification Nos.: C15, D81, G11, Q48

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1 Introduction

Combined heat and power (CHP) technologies bear a substantial potential for increasing energy efficiency and reducing environmental impacts compared to separate heat and power production. To encourage its member states to promote CHP generation, and to provide an attractive framework for highly efficient cogeneration, the European Commission launched the EU CHP Directive 2004/8/EC in February 2004. The implementation of the directive has progressed more slowly than originally expected, but after more than five years, a number of EU member states have introduced support mechanisms to promote CHP technologies. The national promotion schemes are based on different principles, and vary considerably between the member states. In this paper, we first provide an overview of the different CHP promotion schemes used within the European Union. In a next step, we investigate the economic attractiveness of CHP investments in selected countries. In the applied model, we pay particular attention to the typical operational characteristics of CHP generation and to the promotion schemes implemented in different countries. Our intention is to compare CHP investments and to create robust CHP portfolios that are diversified from a regional as well as from a technological perspective. Under "robustness", we understand in this context the ability to generate stable revenues for an investor, irrespective of changes in external effects, such as the impact of fuel and electricity price variation, changes in regulation, or technical change.

The benefits of regional diversification could be of particular interest for international contracting companies that invest in CHP applications in different countries. "Contracting" means the delegation of energy supply-related tasks to a specialized company. Especially in the case of CHP generation for smaller utilities or industrial companies, contracting models have gained attractiveness over the last few years (Helle, 1997). The deeper know-how of contractors in energy-related topics leads in many cases to win-win situations for both parties involved. The technical basic design of the CHP assets is hereby quite similar, but the energy economics conditions, such as the level of commodity prices and the type of promotion scheme, are significantly different in various countries. The findings of this paper give an indication of internationally acting contracting companies regarding countries that provide economically attractive conditions for CHP investments, and to what extent commodity price risks as well as country and regulatory risks can be reduced by a regional diversification of the asset base.

2 Status of CHP implementation in Europe

Combined heat and power generation has been an energy policy focus of the EU for more than twenty years now. Despite of this, the share of electricity from CHP in Europe has increased only very slowly (EEA, 2008). In the 1990s, there was a steady development of new CHP capacity; for instance, between 1994 and 1998, the share of CHP power generation rose significantly from 9% to 11%. However, since then, the contribution of CHP across Europe has stalled, and the indicative 18% target set by the community in 1997 for the year 2010 for the EU-15 (European Commission, 1997) will not be achieved, mostly due to the liberalization of the electricity and gas markets, and less favorable CHP economics caused by rising fossil fuel prices and falling electricity prices. As illustrated in Figure 1, on average, around 11% of electricity supply across Europe is generated by CHP plants. The share of CHP power generation varies considerably across the EU member states, ranging from 42.8% in Denmark to 0% in Malta. The big differences concerning CHP implementation are a response to differences in climate, availability of domestic fuels, industry demands, and variations in building and energy policies. The recently published IEA report "Cogeneration and District Energy" (IEA, 2009) states that there are signs that conditions for CHP across Europe have improved again over the last few years. According to the report, policy makers in various countries have realized the benefits of CHP, and promote its further uptake to achieve policy goals, such as cost savings and carbon reduction targets.

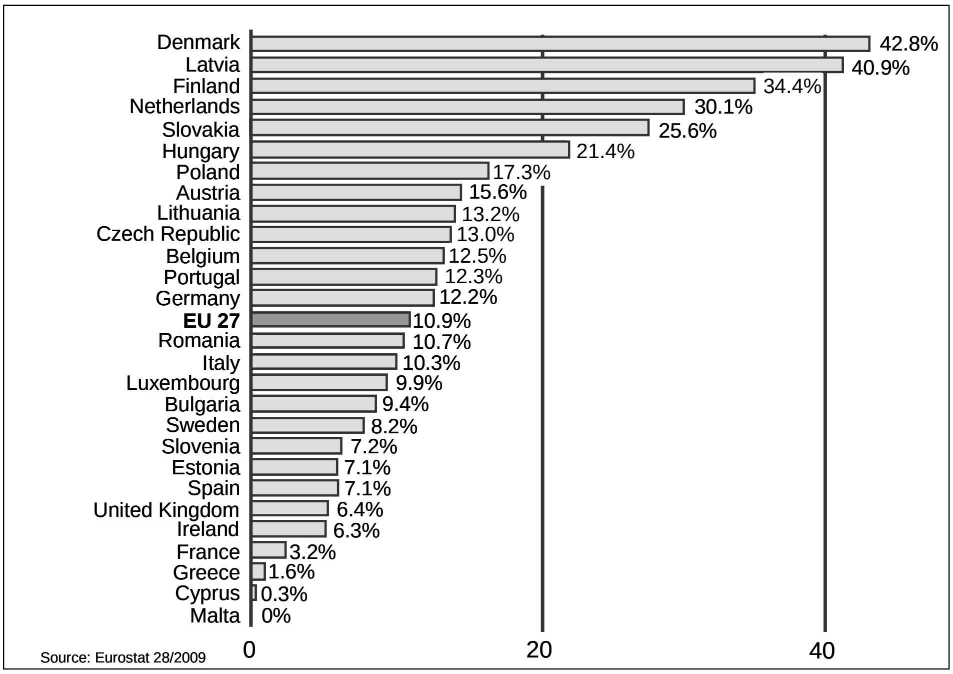

Figure 1: CHP share in power generation in the EU-27 (2007 data), Source: Eurostat (2009)

3 Support mechanisms for CHP generation

In most liberalized energy markets, political support is essential to increase the share of CHP generation. Within the EU, each member state has a unique approach concerning CHP promotion. In this section, we first introduce the most important support mechanisms for CHP within the EU-27 states, after which we provide an overview of which mechanisms are applied in each of the different countries. Finally, we take a more detailed look at the specific promotion schemes applied in the four EU member states with the largest power demand: Germany, France, Italy, and the UK.

3.1 Survey of support mechanisms for CHP

3.1.1 Feed-in tariffs

Feed-in tariffs (FITs) are an energy output-based mechanism designed to provide direct support for CHP applications. CHP plant operators receive a bonus for each kWh of electricity generated or fed into the grid. In general, the bonus can be fixed, be defined as a share of the electricity price, or be indexed against fuel prices. FITs are mostly combined with a purchase obligation that forces the power grid operator to buy CHP-generated electricity on the basis of the current market price. The costs of FITs are usually passed on to the final consumers, and depend on the duration of the promotion for CHP technologies and the level of the tariffs. FITs improve the competitive position of CHP in the market, and encourage investment. The investment incentives also contribute to accelerate the commercialization of emerging CHP technologies. In this way, FITs promote energy efficiency and can help to achieve cost-effective CO_2 emission savings. From an investor's point of view, FITs increase the economic performance and guarantee a secure and predictable cash flow over a determined time period. This contributes to reducing risks and improving returns. More detailed and recent discussions about FITs can be found in Klein et al. (2008), Lesser and Su (2008), or Uran and Krajcar (2009), among others.

3.1.2 Certificate schemes

Certificate schemes for CHP or energy savings are market-based mechanisms that provide additional revenues to the operators of CHP facilities. In its basic form, a state authority places an obligation on electricity suppliers to deliver a certain amount of primary energy savings. In many of the existing certificate schemes, CHP is an acknowledged standard measure to save primary energy. The government can adjust the primary energy saving obligations for electricity supplies on a yearly basis. Realized energy savings are certified by an independent certifying body. The certificates issued confirm the achieved energy savings, and can be traded on a certificate market. This means that each certificate is a unique and traceable commodity that carries a property right over a defined amount of savings. Electricity suppliers that need to meet the saving obligation can either invest in new primary energy-saving measures, or they can purchase the required number of certificates from third parties that have introduced energy efficiency measures. Supply of, and demand for, certificates determine their price. The advantage of certificate schemes is that the actors are given an incentive to find the most efficient and least cost way of achieving the energy-saving obligations. The EU has considered certificate schemes as a possible market approach to increase energy efficiency (European Commission, 2006a). More detailed and recent discussions on energy efficiency certificate mechanisms can be found, for instance, in Bertoldi and Huld (2006), Bertoldi and Rezessy (2006), or Lees (2007).

3.1.3 Investment support

Some EU member states promote CHP generation by granting investment support in the form of allowances for new CHP installations, or the refurbishment of existing CHP plants. The political goal behind this is to reduce the barrier of high up-front investments, and to encourage capital-constrained organizations to invest in CHP, and to facilitate the market introduction of emerging low-carbon technologies, such as CHP from renewables, or micro-CHP. In order to receive investment support, the CHP installations have to meet defined criteria, e.g. defined primary energy savings or minimum annual efficiencies of energy use. The German investment support mechanism for micro-CHP installations (< 50 kW_{el}) is also linked to the obligation not to exceed a defined level of greenhouse gas emissions. The allowance that an investor can receive often depends on the size of the plant, measured by the electrical capacity and the number of full-load hours (e.g. electrical output p.a.). The level of allowance has to be reviewed regularly and needs to reflect changing technological and market conditions.

3.1.4 Fiscal support

Fiscal support for investments in CHP plants is generally possible in two different forms. On the one hand, CHP can receive preferential treatment concerning the taxation of the used fuels or the generated electricity. In some countries, CHP plants are eligible for a 100% tax exemption. The second type of fiscal support is an accelerated depreciation for new CHP investments. This has an indirect effect on the profitability of the investment, as the profits of the first years are lower, and thus the corporate tax due is reduced. Fiscal support can lower the risk and increase the financial attractiveness of investments in CHP. Sometimes the plants need to fulfill defined efficiency criteria or a minimum annual usage rate to receive the tax benefits. An advantage of promotion by fiscal support is that the administrative effort for CHP developers is comparably low. A disadvantage is that a tax relief can only be achieved if a sufficiently high tax burden actually exists.

3.1.5 Beneficial allocation of CO_2 emission permits

CHP plants with a thermal capacity of more than 20 MW are obliged to participate in the EU Emission Trading Scheme (ETS). For these plants, an indirect promotion can be given via the allocation of free emission permits (*grandfathering*). Up to now, the allocation of free emission permits is based on the rules stipulated in the National Allocation Plans (NAPs) and, therefore, differs significantly across the EU member states, as described for instance in IEA (2008) or Betz et al. (2004). In principle, there are a number of possible options as to how CHP can be treated in terms of the allocation of free certificates:

- *Free allocation of permits equivalent to the actual carbon savings of the CHP plant*. CHP plant operators are required to submit permits for all of their emissions, but receive a free allocation of permits equivalent to the carbon emissions saved.
- *Free allocation of permits equivalent to the electrical output of the CHP plant*. CHP plant operators are required to buy permits for heat production, amounting to the equivalent of a situation with a stand-alone onsite heat boiler and electricity from the grid.
- *Free allocation of permits equivalent to the heat output of the CHP plant*. CHP plant operators are required to buy permits according to the electrical output of the plant, but receive free allocation equivalent to the heat output.
- *100% free permits for the CHP plant*.

CHP plant operators receive the free allocation of permits for all greenhouse gas emissions released during the operation of the plant.

As the allocation rules for the current second period of EU ETS (2009-2012) are fixed, how CHP will be treated in the next period starting from 2013 onwards will be decisive. The detailed allocation rules are currently under discussion. More information concerning the treatment of CHP in emission trading can be found in IEA (2008).

3.2 Examples of the application of CHP support mechanisms in Europe

The above-described support mechanisms are applied in different variants within the EU-27 states. Table 1 provides an overview of the CHP support mechanisms currently applied in the respective countries. A more detailed description of the support mechanisms can be found in Appendix B.

For the following Mean-Variance Portfolio (MVP) investigation, we focus on Germany, France, Italy, and the UK. These countries represent the four markets with the largest power demand in Europe, and show significant differences concerning the support mechanisms in place. Therefore, in a next step, we introduce the currently established CHP promotion schemes in the selected countries on a more detailed level.

Table 1: Support mechanism for CHP in EU member states

Country	Feed-in tariff	Certificate scheme	Investment support	Fiscal support
Austria	X		X [a]	
Belgium		X [b]		X
Bulgaria	X [c]			
Cyprus			X [d]	
Czech Republic	X		X	
Denmark	X [f]			X [e]
Estonia	X [g]			
Finland			X [d]	X
France	X [h]			X
Germany	X		X [i]	X
Greece	X [j]			
Hungary	X [c]		X	X
Ireland			X	

Italy		X		X
Latvia	X [k]			
Lithuania	X [k]			
Luxembourg	X [l]		X [d]	
Malta				
Netherlands	X		X	X
Poland		X		
Portugal	X			
Romania				
Slovakia	X [m]			
Slovenia	X [n]			X
Spain	X			X [d]
Sweden		X [d]		X
United Kingdom				X

Notes:
a) only CHP < 2 MW_{el}
b) dependent on the region
c) only CHP < 50 MW_{el}
d) only biomass CHP
e) only for micro-CHP
f) only micro- and biomass CHP
g) for replacements < 10 MW_{el}
h) only existing non-gas fuelled fossil plants
i) only CHP < 50 kW_{el}
j) only CHP < 35 MW_{el}
k) only district heating
l) only CHP < 1.5 MW_{el}
m) only industrial CHP
n) only industrial CHP and DH

Sources: see Appendix B

3.2.1 CHP promotion in Germany

As already shown in Table 1, CHP promotion in Germany includes several different support mechanisms. The new German CHP Act that entered into force on January 1, 2009, guarantees feed-in tariffs for high-efficiency CHP over a defined period of time, irrespective of whether the power produced is fed into the grid or used on-site for self-consumption. The level of the feed-in tariffs depends on the size of the plant measured by the electrical net capacity (Table 2). The usage of biomass fuels can additionally increase the guaranteed remuneration.

Micro-CHP plants in Germany with a capacity of below 50 kW_{el} receive, in addition to feed-in-tariffs, a capital grant of € 200,000 maximum. To obtain the full support, the micro-CHP plant needs to fulfill several criteria, such as a minimum amount of primary energy savings and a minimum annual load factor. Large German CHP plants with a capacity of more than 20 MW_{th}, that are covered by the European Union Emission Trading Scheme (EU ETS), currently benefit from the allocation mechanism for CO_2 certificates. The German NAP guarantees CHP plants a privileged allocation of certificates according to the double benchmark principle. This means that CHP plants receive CO_2 allowances for the power produced and, additionally, further allowances for the heat produced (BMU, 2007). The German grid code guarantees operators of decentralized generation units (including CHP) an additional compensation for avoided grid usage if they feed directly into the distribution grid. The level of the allowance depends on the specific conditions in the respective distribution grid. More detailed information concerning the promotion of CHP in Germany, and a portfolio analysis of different CHP technologies can be found in Westner and Madlener (2009).

Table 2: Promotion of CHP according to the German CHP Act 2008 (Gesetz zur Förderung der Kraft-Wärme-Koppelung, 2008)

Plant size	**Remuneration**
≤ 50 kW_{el}	5.11 €ct/kWh for the duration of 10 years, no degression
≤ 2 MW_{el}	2.1 €ct/kWh for the duration of 6 years or a maximum of 30,000 full-load hours 5.11 €ct/kWh for the first 50 kW
> 2 MW_{el}	1.5 €ct/kWh for the duration of 6 years or a maximum of 30,000 full-load hours Exception industrial applications: Duration only 4 years or a maximum 30,000 full-load hours 2.1 €ct/kWh for the first 2 MW, 5.11 ct/kWh for the first 50 kW

3.2.2 CHP promotion in France

In comparison to other European countries, the promotion schemes for CHP in France are less attractive. For new CHP plants with a capacity of below 12 MW_{el} there exists a purchase obligation which forces state-owned utilities, such as EdF, to purchase the produced electrical energy by paying the current market price. Purchase obligations reduce the risk and, as a consequence, the investors can request a lower return on the investment to cover their risk. Existing CHP plants that are not gas-fueled, and plants fueled with biomass receive a guaranteed feed-in tariff that is defined individually for each site. Additionally, there exists the opportunity of an accelerated depreciation of the investment, and in some areas CHP generation is exempted from local business tax.

Due to the low level of governmental support, the high share of nuclear generation, and the existence of a vertically integrated monopoly, CHP has not developed strongly over the last couple of years. In 1997, the French government introduced a special regime for CHP that guaranteed a fixed feed-in tariff for electricity from CHP plants. This caused a temporary boost in CHP activities, and more than 1,000 MW_{el} of capacity was developed between 1997 and 2000. However, after November 1998, the promotion was withdrawn for new projects, which caused a strong decline in new CHP construction activities. In general, the conditions for new CHP generation in France are currently less attractive compared to other EU member states. This is also reflected in the low share of 3.2% of CHP generation in the total power production. More information concerning treatment of CHP in France is available in a benchmarking report published by COGEN Europe (2006).

3.2.3 CHP promotion in Italy

In 2005, the Italian government introduced a system to increase energy efficiency based on tradable certificates for energy savings. The so-called White Certificates (WhC) are issued for various kinds of energy efficiency measures, including CHP and district heating. The Italian certificate scheme has been described in a number of sources, e.g., Bertoldi and Rezessy (2006), Bertoldi and Huld (2006), and Capozza (2006). For brevity, we do not provide a complete overview of the Italian certificate scheme, but instead focus on the details of the scheme for CHP generation only.

The relevant parameters for the allocation of WhCs are the achieved primary energy savings. Primary energy savings of CHP are defined as the difference between primary energy demand of separate generation of power and heat, and primary energy demand of combined generation. They are calculated based on the following formula, as stipulated in the 2004 EU directive on the promotion of cogeneration (European Commission, 2004):

$$PES = \left(1 - \frac{1}{\frac{\eta_{CHP\_H}}{\eta_{Ref\_H}} + \frac{\eta_{CHP\_E}}{\eta_{Ref\_E}}} \right) \cdot 100\% \quad . \qquad (1)$$

Primary energy savings (PES) depend on the relation between the heat efficiency of cogeneration production, η_{CHP_H} (defined as annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration), and the efficiency reference value for separate heat production, η_{Ref_H}. Moreover, they also depend on the relation between electrical efficiency of the cogeneration production, η_{CHP_E} (defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration), and the efficiency reference value for separate electricity production, η_{Ref_E}. The primary energy savings and the respective allocation of WhCs are calculated by applying the harmonized efficiency reference values provided in a decision of the European Commission (European Commission, 2006b). Table 3 depicts an exemplary calculation of primary energy savings and the number of WhCs allocated to a generic coal-fired and a generic gas-fired CHP plant, respectively, of the given size and technology.

Table 3: Primary energy savings of CHP and White Certificate allocation in Italy

Fuel type	**Coal**	**Natural gas**
Technology	Supercritical coal plant	CCGT plant
Capacity [MW]	50	50
Capacity utilization [%]	80	80
Overall efficiency	0.6	0.8
Electrical efficiency	0.45	0.56
Primary energy savings per year [GWh]	87	141
No. of White Certificates per year	7,422	12,085

Note: Own calculation based on exemplary assumptions for coal- and gas-fired power plants

The financial support of CHP depends on the market price of the WhCs. Market results for WhC prices have been available since March 2006. The average price for traded certificates in the period from January 2008 – April 2009 was € 77 (GME, 2009).

3.2.4 CHP promotion in the UK

In April 2001, the UK government introduced the Climate Change Levy (CCL), a tax on electricity, gas, coal, and liquefied petroleum gas (LPG). The intention of the levy, only applicable in the non-domestic sector, is to encourage businesses to increase energy efficiency and to reduce the carbon emissions in the UK. Each commodity attracts a different tax rate based on its energy contents. The highest tax rate has to be paid for electrical energy; this is justified by the considerable proportion of primary energy that is lost in combustion, transmission, and distribution of electrical power. The current tax rates of the levy are reported in Table 4.

Table 4: CCL rates for different fuels

Commodity	**Legal rate**	**Rate on an equivalent energy basis [pence/kWh]**
Electricity	0.43 pence per kilowatt hour [kWh]	0.43
Natural gas as supplied by a gas utility	0.15 pence per kWh	0.15
Liquefied petroleum gas for heating	0.96 pence per kilogram [kg]	0.07
Solid fuel (e.g. coal and coke)	1.17 pence per kg	0.15

Note: For the investigation in this paper, we assume an exchange rate of 1 British Pound = 1.164 Euros (July 18, 2009)

Source: HM Treasury (2006)

Exemptions from CCL have been introduced to increase the usage of less-polluting alternative energy sources. These exemptions cover, among other things, also good-quality combined heat and power plants and CHP-generated electricity sold via the grid. This makes CHP more competitive compared to the conventional (separate) generation of heat and power. In order to receive the tax benefits, good quality CHP needs to be registered and certified within the CHP Quality Assurance (CHPQA) program. In the case where the generated electricity is exported from the CHP site to an external customer, the market regulator issues levy exemption certificates to signify the tax benefits. More information concerning the treatment of CHP generation in the CCL scheme can be found, among other sources, in HM Treasury (2006) and on the website of the Quality Assurance for CHP, a governmental institution responsible for monitoring and certification of good quality CHP (CHPQA, 2009). In addition to the benefits based on CCL exemption, new CHP installations in the UK receive a partly free allocation of CO_2 emission certificates from the New Entrant Reserve (NER). Micro-CHP installations are supported by the UK government via a reduced value added tax rate (VAT).

4 Application of MVP theory in the context of power generation

In our investigation, we apply Mean-Variance Portfolio (MVP) theory with respect to regional diversification of investment opportunities in CHP technologies in Europe. The motivation for doing so is that investors in CHP generation need to decide from a return-risk perspective which countries and which technologies offer the best opportunities. We pay no attention to technological diversification of investments, as was done in Westner and Madlener (2009), and focus instead on regional diversification. A regionally mixed portfolio could be advantageous, as market conditions for CHP generation differ significantly between the various European energy markets. Our investigation covers CHP investments in Germany, France, Italy, and the UK. In each country, we pay respect to the above-described CHP promotion schemes. Particularly, we investigate two different kinds of established CHP technologies: Combined-cycle gas turbines (CCGT) with heat and power utilization and engine-CHP. Our analysis is based on the expected net present value (NPV). The expected NPV of the mixed portfolio is calculated on the basis of the following formula:

$$E(NPV_P) = \sum_{i=1}^{n} \alpha_i \cdot E(NPV_i) \quad . \tag{2}$$

The expected NPV of the mixed portfolio P containing n assets $E(NPV_P)$, is calculated on the basis of the NPVs of the single CHP investment options i with their expected NPV, $E(NPV_i)$. All single shares of the different portfolio components together represent 100% of the portfolio, and thus sum up to unity:

$$\sum_{i=1}^{n} \alpha_i = 1 \ . \tag{3}$$

The standard deviation of the mixed portfolio σ_P is defined by the following formula:

$$\sigma_p = \sqrt{\sum_{i=1}^{n} \alpha_i^2 \cdot \sigma_i^2 + \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} \alpha_i \cdot \alpha_j \cdot \sigma_i \cdot \sigma_j \cdot \rho_{ij}} \quad ,(4)$$

where σ_i represents the standard deviation of CHP investment option i, and ρ_{ij} the correlation between the NPVs of different CHP investment options in the portfolio.

There are several research papers available in which MVP theory has been applied in the context of power generation portfolios. Markowitz (1952) marks the beginning of modern portfolio theory. Over time, portfolio theory has also been applied to non-financial assets. One of the first applications in the context of power generation portfolios is Awerbuch and Berger (2003). They investigate the generation portfolio of the European Union (EU-15) and show with their model the portfolio effects of various generation technologies. Krey and Zweifel (2006) determine efficient power generation mixes for Switzerland and the United States by applying MVP theory. In their investigation, they consider correlated shocks in electricity generation costs by usage of the seemingly unrelated regression estimation (SURE) method. Roques et al. (2008) put the focus of their investigation not on existing generation portfolios but on investments in new generation technologies in the UK. They focus on base-load technologies and consider the NPV and its standard deviation as target variables for their analysis. Madlener and Wenk (2008) investigate the future development of the power generation portfolio in Switzerland and identify efficient investment options for the electricity supply sector. By applying MVP theory, their study covers existing power generation technologies as well as new development options, and differentiates between base-load and peak-load technologies. A more detailed description of literature available on this topic can be found in Westner and Madlener (2009). In that paper, we provide a detailed description of currently available CHP technologies, and investigate portfolios consisting of different kinds of CHP generation in Germany on the basis of NPVs and annual returns. We find that CCGT-CHP and engine-CHP are the most attractive CHP technologies from a return perspective and that a diversification of the portfolio with different kinds of CHP technologies can contribute to stabilize portfolio returns. On the basis of these results we conclude that a major stake of additional new German CHP capacity will be installed for industrial applications, although it seems unlikely that the CHP policy targets are going to be achieved given present CHP promotion policy.

5 Definition of input parameters

In this section, we define the input parameters for the financial model and the subsequent portfolio investigation of CHP technologies. This includes commodity prices and technical/operational parameters as well as financial parameters used for cash-flow modeling. Risks resulting from plant construction, such as a cost overrun of the investment budget, or longer lead times than expected, are not within the scope of our research, as these are typically independent from the country studied.

5.1 Commodity prices

Costs and revenues of power generation in liberalized electricity markets depend to a high degree on uncertainties at the commodity markets for power, fuels, and CO_2 allowances. The financial model and the Monte Carlo simulation carried out in this paper are based on historical price developments in the respective markets.

Table 5: Characteristics of commodity prices used for MVP investigation

Country	Commodity	Time period	Periodicity	Mean	Standard deviation	Assumed distribution
Germany	Power [a]	1 Jan. 2007 – 31 Dec. 2008	Hourly	54.34	31.27	log-normal
	Natural gas [b]	1 Oct. 2006 – 31 Dec. 2008	Monthly	20.77	2.62	log-normal
	CO_2 certificates [c]	1 Jan. 2007 – 31 Dec. 2008	Daily	21.36	3.83	log-normal
France	Power [d]	1 Jan. 2007 – 31 Dec. 2008	Hourly	55.03	42.78	log-normal
	Natural gas [e]	1 Jan. 2006 – 31 Dec. 2008	Monthly	20.71	7.21	log-normal
	CO_2 certificates [c]	1 Jan. 2007 – 31 Dec. 2008	Daily	21.36	3.83	log-normal
Italy	Power [f]	1 Jan. 2007 – 31 Dec. 2008	Hourly	67.00	35.92	log-normal
	Natural gas [g]	1 Oct. 2006 – 30 Sep. 2008	Monthly	26.13	3.15	log-normal
	CO_2 certificates [c]	1 Jan. 2007 – 31 Dec. 2008	Daily	21.36	3.83	log-normal
	White Certificates [h]	1 Jan. 2007 – 31 Dec. 2008	Daily	77.70	9.55	normal
UK	Power [i]	1 Jan. 2007 – 31 Dec. 2008	Hourly	56.65	35.64	log-normal
	Natural gas [j]	1 Oct. 2006 – 31 Dec. 2008	Monthly	20.33	7.27	log-normal
	CO_2 certificates [c]	1 Jan. 2007 – 31 Dec. 2008	Daily	21.36	3.83	log-normal

Sources: a) EEX Day-Ahead Power Price
b) German Import Price
c) EEX Future EUA Period 2
d) EPEX Spot Auction Prices
e) Point d'Echange de Gaz (PEG North)
f) GME Day-Ahead Power Price
g) Heren Energy
h) GME White Certificate Price
i) ELEXON Electricity Day-Ahead Spot Price
j) UK NBP Frontmonth

Table 5 contains the characteristics of commodity prices that are used as a basis for the following investigation. Due to the fact that up to now no liquid natural gas market with transparent prices exists in Italy, we take the price information for natural gas in Italy from the Heren gas market report (Heren Energy, 2008). All other commodity prices reported in Table

5 are based on price data available at the energy exchange of the respective countries. Prices for the produced heat are derived on the basis of gas-fired heat boilers, as described in Westner and Madlener (2009).

5.2 Technical and operational parameters

In our investigation, we differentiate between two well-established CHP technologies. These are combined-cycle gas turbine CHP (CCGT-CHP) and engine-CHP. Table 6 contains the relevant technical and operational input data of the selected technologies.

Table 6: Technical and operational input parameters of CHP technologies

		CCGT-CHP	**Engine-CHP**
Electrical capacity [MW_{el}]		50	0.5
Heat capacity [MW_{th}]		50	0.75
Fuel type		Natural gas	Natural gas
Electrical efficiency		0.56	0.36
Global efficiency		0.8	0.90
Fixed operation & maintenance cost [€/kW_{el}]		36	40
Variable operation & maintenance cost [€/MWh]		1	0.7
Specific CHP promotion [€/MWh_{el}]		15	21
Specific CO_2 emissions [t CO_2/MWh_{el}]		0.360	0.495
Investment cost [€/kW_{el}]		1,300	800
Depreciation period [a]		30	20
Capacity utilization for power and heat generation [%]	Mean	80	50
	Standard deviation	5.7	5.7
	Distribution	Normal	Normal

Source: Operational data derived from existing CHP plants

The operational parameters for the CCGT-CHP plant given in Table 6 are typical for industrial applications. Plants of this size with a high capacity utilization of 80% are common in the chemical, steel, food, and paper & pulp industries (Bonilla et al., 2003). Engine-CHP is often applied for local heat systems or smaller industrial applications. They are usually dimensioned according to the heat demand with the consequence of a lower capacity utilization of typically around 50%.

5.3 Financial parameters of the cash flow model

The financial parameters and assumptions of the applied cash flow model are identical to the investigation carried out in Westner and Madlener (2009). Therefore, we refrain from a detailed description of the applied financial model. In our model, we take the NPV as the basis for the evaluation of CHP investment options in different countries. NPVs are gained by aggregation of the discounted annual cash flows of the CHP plants. Our NPV-based portfolio analysis refers only to new investments in CHP technologies; the option of buying existing CHP assets is not considered. NPVs include the investment stream during the construction phase, and the annual cash flows during the operation phase of the plant. The annual cash flows during the operation phase comprise all revenues and costs. To determine the costs for CO_2 emissions, we need to make assumptions concerning the future allocation rules of CO_2 allowances. Until the end of the second ETS trading period in 2012, we consider in our model the allocation rules given in the NAPs. From 2013 onwards, we assume a free allocation of permits equivalent to the heat output of the CHP plant. This option is currently under discussion, and it seems likely that it could be implemented after 2012.

6 MVP analysis on CHP investment options

6.1 Results from the financial model

Based on the above-defined input parameters and assumptions for each investment option, the financial model generates a probability distribution of the NPV. Table 7 reports the NPV, the standard deviation of the NPV, and the internal rate of return (IRR) obtained. A more detailed summary of the results gained from the Monte Carlo simulations can be found in Appendix A.

Table 7: Results from NPV calculation of CHP investments in different countries

	Investment cost [€/kW]	**NPV** [€/kW]	**Standard deviation NPV** [€/kW]	**IRR** [%]
CCGT-CHP				
Germany	1,300	182	25.16	14.0
France	1,300	3	29.12	0.2
Italy	1,300	109	27.07	8.4
UK	1,300	60	26.73	4.6
Engine-CHP				
Germany	800	96	21.95	12.0
France	800	-205	24.72	-25.6
Italy	800	42	23.73	5.2
UK	800	-164	22.99	-20.6

The results show that the profitability of CHP investments varies significantly between different markets. This is mainly due to the different price levels for power and natural gas, and to the differences in CHP promotion in the respective countries. By comparing the results, one can see that the profitability of CCGT-CHP is in all markets better than the profitability of engine-CHP. The highest NPVs and IRRs can be achieved in Germany (NPV of 182 €/kW and 96 €/kW, respectively). The second most attractive market is Italy (NPV of 109 €/kW vs. 42 €/kW), followed by the UK (NPV of 60 €/kW vs. -164 €/kW) and France. The profitability of CHP in France (NPV of 3 €/kW vs. -205 €/kW) is quite poor due to the level of commodity prices and the fact that currently there is no attractive support mechanism in place.

6.2 Sensitivity analysis

A sensitivity analysis of the results (with a variation of +/-10%) shows that power prices have the most dominant influence on the NPV. The influence of prices for natural gas or CO_2 certificates is also significant but less than the power price level. The effect of the existing support mechanisms on the profitability of CHP investments in Germany and Italy is in any case lower than the effect of commodity prices. The results of the sensitivity analysis for CCGT-CHP and engine-CHP in Germany and Italy are shown in Figure 2.

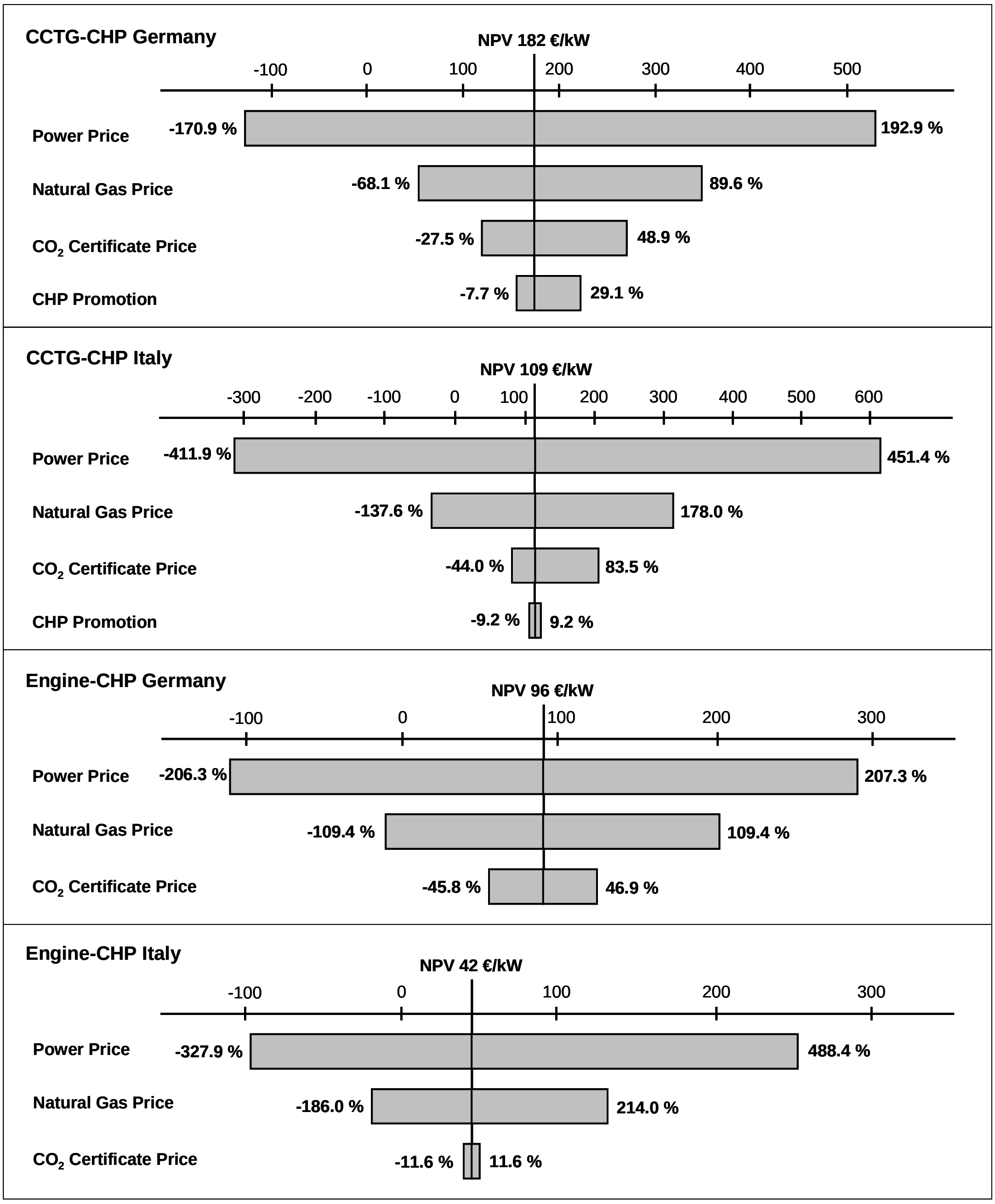

Figure 2: Sensitivity analysis: Impact of a 10% change of the respective variable on the NPV

6.3 Correlation Coefficients

In order to determine the efficient frontier, it is also essential to determine the correlation coefficients between the NPVs for different investment options. The basis for the correlation between NPVs is the correlation between the input parameters, especially the correlation of prices for power, natural gas, and emission allowances in the various countries. Correlation factors are gained with the financial model by means of econometric regression analysis. The results are presented in Table 8.

Table 8: Correlation coefficients of NPVs among the various investment options

	Germany	France	Italy	UK
CCGT-CHP				
Germany	1.00	0.98	0.98	0.99
France		1.00	0.99	0.99
Italy			1.00	0.99
UK				1.00
Engine-CHP				
Germany	1.00	0.00	-0.49	-0.56
France		1.00	0.38	0.39
Italy			1.00	0.98
UK				1.00

According to our model, the correlation coefficients between CCGT-CHP investment options in the selected countries are relatively high. The reason for this is that country-specific components, such as revenues from CHP promotion, are relatively small compared to total revenues. More dominant components, such as fuel costs or revenues from power sales, show a high correlation in the selected countries. As a consequence, also the NPVs are strongly correlated. For engine-CHP, the situation is slightly different, in that uncorrelated influences of country-specific effects, like those that arise from the CHP promotion schemes, represent a higher stake of total revenues.

6.4 Results MVP analysis

We now analyze the results of the financial model, and identify beneficial investment options from a return-risk perspective by applying MVP theory.

6.4.1 CCGT-CHP

First, we apply the MVP approach on investments in new CCGT-CHP plants. Characteristic attributes of the plant, such as the size given by the installed capacity, the capacity utilization, and the correlation coefficients between the NPVs of the different options, have a significant impact on the results of the portfolio analysis, as shown in Figure 3. Each dot in the diagram represents a return-risk combination for a mixed portfolio of CCGT-CHP investments in various countries. The portfolios where all assets are located in one single country are marked in the diagram as 100% portfolios, i.e. portfolios that are not regionally diversified. The results were obtained from a Monte Carlo simulation with 100,000 runs.

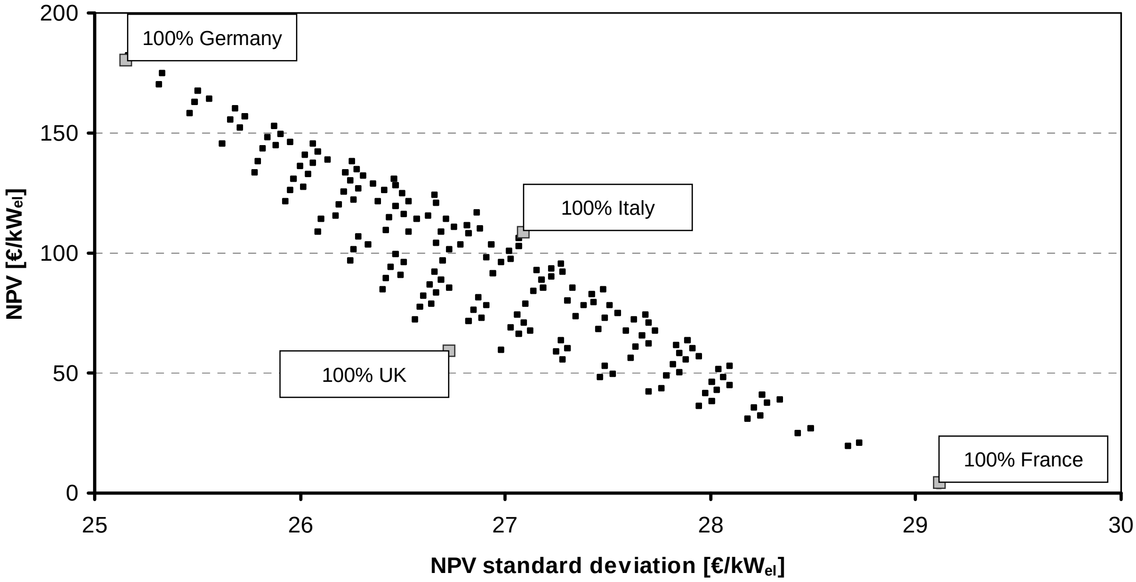

Figure 3: MVP analysis of CCGT-CHP portfolios with assets in the four selected countries

The portfolio effect of CCGT-CHP investments in different countries is low, due to the high correlation between the investment options (as shown in Table 8) and the fact that CCGT-CHP in Germany generates the highest NPV as well as the lowest standard deviation of the NPV. As a consequence, it is impossible to reduce the risk exposure through diversification of CHP investments in the other countries considered, and there exists no efficiency frontier for CCGT-CHP portfolios. The optimal portfolio from a return-risk perspective is a portfolio consisting of 100% CCGT-CHP in Germany. Due to the beneficial promotion and the commodity prices assumed, the framework conditions for CCGT-CHP in Germany are more favorable than in the three other European markets investigated.

6.4.2 Engine-CHP

As a next step, we report the findings of the portfolio selection for engine-CHP applications, for which we get a different result. In countries like Germany, smaller CHP applications, such as engine-CHP, receive relatively more promotion than larger plants; in addition, the capacity utilization is lower compared to CCGT-CHP plants. This reduces the influence of commodity prices on the economics of engine-CHP investments, and strengthens the influence of the revenues through CHP promotion. As a consequence, there exist significant differences in the correlation coefficients between the NPVs of engine-CHP applications in different countries, and a significant portfolio effect can be noticed. The results from the Monte Carlo simulation (100,000 runs) are depicted in Figure 4.

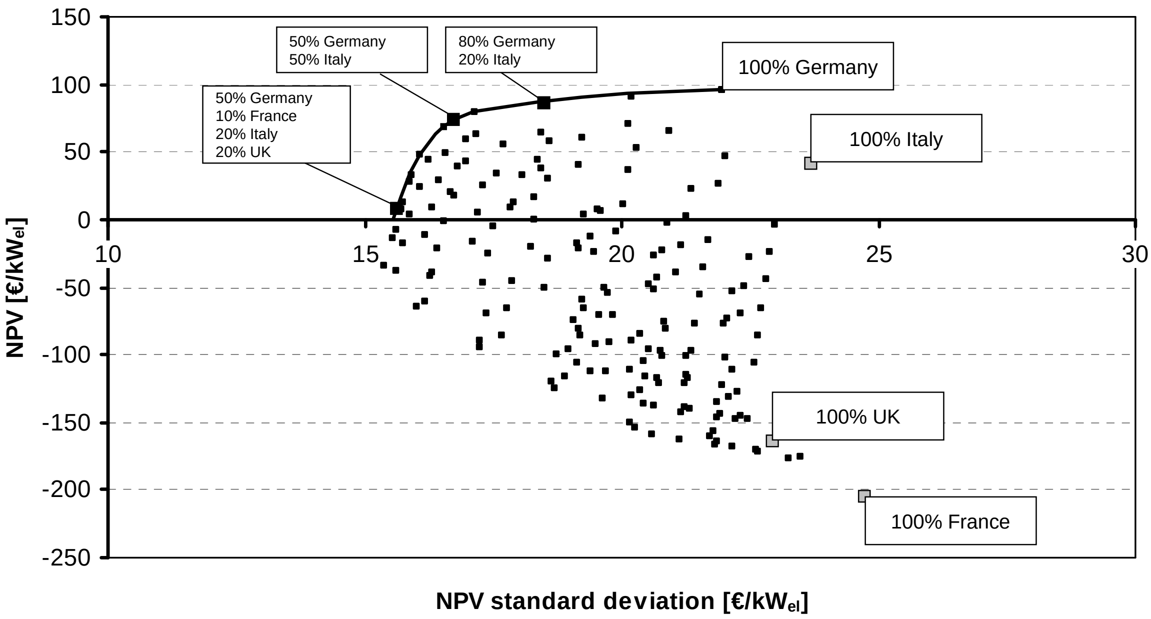

Figure 4: MVP analysis of engine-CHP portfolios with assets in the four selected countries

In the UK and France, the NPVs of engine-CHP applications are negative, due to the level of commodity prices and a less beneficial promotion policy. Therefore, many portfolio combinations that include assets in the UK and France are not profitable and show a negative NPV. The portfolio with the highest NPV again represents a portfolio that consists 100% of CHP assets located in Germany. This portfolio reaches an IRR of 12%. For engine-CHP, we can notice a clear portfolio effect and that a regional mix can contribute to reduce the risk exposure. The portfolio with the lowest NPV standard deviation has a negative NPV. The first portfolio on the efficiency frontier with a positive NPV consists of an asset mix with engine-CHP plants in Germany (50%), France (10%), Italy (20%), and the UK (20%). The NPV of this portfolio is 3 €/kW$_{el}$, which corresponds to an IRR of about 0.4%.

7 Conclusion and policy implications

Our investigation provides some insights for investors in CHP technology or contracting companies concerning the benefits of regional diversification in cogeneration assets. The results obtained clearly show that the impact of the established promotion schemes on the economic attractiveness of CHP investments is lower than the impact of the general level of commodity prices in the respective market. Nevertheless, CHP promotion contributes to increased profitability, and in many cases turns the balance in favor of new investments in CHP generation. The analysis of CHP promotion schemes applied in the EU-27 shows a wide range of support mechanisms that are based on different principles. The results from the financial model show that the economic attractiveness of CHP investments varies significantly between the four selected energy markets and two CHP technologies chosen in our investigation. In all markets, the specific NPVs in €/kW_{el} of CCGT-CHP are higher compared to the NPVs of engine-CHP applications. After implementation of the new CHP law in Germany in early 2009, the German market currently offers by far the most attractive investment options for CHP generation, followed by Italy, the UK, and France.

The subsequent MVP analysis based on the results of the financial model comes to the conclusion that regional diversification is only conditionally able to reduce the risk exposure of CHP portfolios. The degree of diversification depends on the chosen technology. From our analysis, we conclude that a regional diversification of investments in CCGT-CHP is less meaningful from a return-risk perspective than a regional diversification of engine-CHP assets.

These findings raise the general question of whether it is attractive for contractors to build up CHP portfolios that are regionally diversified. To answer this question, effects from a technological diversification of different kinds of CHP technologies, as is investigated in Westner and Madlener (2009), and effects of an aggregation of small single CHP units to virtual power plants (VPPs) have to be considered as well. Especially the quantification of the economic benefit of VPPs for utilities reveals a fruitful area where further research is urgently needed.

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Appendix A: Results Monte Carlo simulation of CHP technologies

Table A.1: Results based on NPV [€/kW$_{el}$] for CCGT-CHP, by country

	Germany	**France**	**Italy**	**UK**
No. of runs	100,000	100,000	100,000	100,000
Mean	182.18	2.79	109.06	60.00
Median	145.08	-71.34	74.95	10.57
Mode	---	---	---	---
Standard deviation	25.16	29.12	27.07	26.73
Variance	633.22	847.87	733.00	714.31
Skewness	0.3821	0.5850	0.3126	0.4295
Kurtosis	3.43	3.81	3.31	3.47
Coeff. of variability	3.48	303.36	6.72	11.90
Minimum	-45.76	-53.60	-50.68	-51.37
Maximum	68.77	78.01	71.76	75.66
Range width	114.53	131.61	122.44	127.03

Table A.2: Results based on NPV [€/kW$_{el}$] for engine-CHP, by country

	Germany	**France**	**Italy**	**UK**
No. of runs	100,000	100,000	100,000	100,000
Mean	96.22	-205.18	41.55	-164.49
Median	75.61	-242.64	26.43	-185.91
Mode	---	---	---	---
Standard deviation	21.95	24.72	23.73	22.99
Variance	481.63	611.07	563.11	528.45
Skewness	0.2577	0.4253	0.1721	0.2715
Kurtosis	3.31	3.69	3.19	3.40
Coeff. of variability	5.01	-2.98	13.55	-3.21
Minimum	-44.66	-49.60	-46.90	-50.28
Maximum	56.09	64.92	58.03	60.43
Range width	100.75	114.53	104.93	110.70

Appendix B: Overview CHP policies in the EU-27 countries

Country	Status (2006)	CHP potential	Political target	CHP promotion policy
Austria	• Installed CHP capacity: 3.27 GW_{el} • CHP power generation: 10.24 TWh • CHP heat production: 98.9 PJ • CHP-share in power generation: 16.1%	National potential study carried out in 2005 identified a technical feasible CHP potential of 7.3 Ge_l for on-site cogeneration and of 4.4 GW_{el} for district heating	No specific CHP target	• Legal framework given within the "Ökostromgesetz" • Feed-in tariffs only for CHP applications used for public district heating (DH) and under the condition of achieved primary energy savings and CO_2 reduction in comparison to separate generation of power and heat • Investment support for fossil fuelled CHP <2 MW_{th} and biomass CHP
Belgium	• Installed CHP capacity: 1.64 GW_{el} • CHP power generation: 7.44 TWh • CHP heat production: 74.5 PJ • CHP-share in power generation: 8.7%	Potential studies carried out in 2005 provide a regional differentiation of the feasible CHP potential: • Flanders 1,100 MW_{el} • Wallonia 320 MW_{el} • Brussels 110 MW_{el}	**Flanders:** Increase CHP share in power generation up to 16 % by 2012	Fragmented promotion schemes with different conditions for each region **Flanders:** • Tradable certificate scheme for CHP • Certificates are awarded for primary energy savings realized compared to reference technologies for separate power and heat generation • Tax reduction from taxable income **Wallonia:** • Tradable green certificates for CHP, or direct subsidies • Focus on promotion of micro-cogeneration systems and high-efficiency wood-burning CHP • Tax reduction from taxable income
Bulgaria	• Installed CHP capacity: 1.14 GW_{el} • CHP power generation: 2.77 TWh • CHP heat production: 48.0 PJ • CHP-share in power generation: 6.0%	No study has been carried out	No specific CHP target	• Legal framework is given through the "Energy and Energy Efficiency Act" • Feed-in tariffs for CHP capacities smaller than 50 MW_{el} • Purchase obligation for co-generated electricity by electricity transmission and distribution companies
Cyprus	• Installed CHP capacity: 0.01 GW_{el} • CHP power generation: 0.01 TWh • CHP heat production: 0.1 • CHP-share in power generation: 0.3%	No information	No specific CHP target	• Policy support is limited to investment grants primarily for bio fuels
Czech Republic	• Installed CHP capacity: 4.87 GW_{el} • CHP power generation: 12.71 TWh • CHP heat production: 143.2 PJ • CHP-share in power generation: 15.1%	National potential study was carried out in 2004 and identified additional CHP capacity of 2.84 GW_{el}	General target of reducing energy intensity of the national economy	• Feed-in tariffs for fossil and renewable CHP units depend on the size of the plant based on the electric capacity • Investment support up to 15% of the total investments in CHP

Country	Status (2006)	CHP potential	Political target	CHP promotion policy
Denmark	• Installed CHP capacity: 5.70 GW_{el} • CHP power generation: 18.63 TWh • CHP heat production: 117.2 PJ • CHP-share in power generation: 40.7%	• Due to the already high CHP share in power generation, only little expansion is possible • Only possibility for further growth is in the area of micro cogeneration	Reduction of total energy consumption by 4% based on 2006 figures	• Indirect support through high taxation of fuels used for heat only generation • Feed-in tariffs for micro-CHP and CHP applications fired with wood chips, straw, or biogas • Tax reduction for small-scale CHP
Estonia	• Installed CHP capacity: 1.6 GW_{el} • CHP power generation: 1.04 TWh • CHP heat production: 11.6 PJ • CHP-share in power generation: 10.7%	No information	No specific CHP target	• Amendment to the electricity market act from May 2007 improved conditions for CHP generation • Feed-in tariffs for CHP fuelled with renewable energy sources (peat, waste, or oil shale gas) • Feed-in tariffs for CHP plants with less than 10 MW_{el} that replace former heat-only boiler (HOB) plants • Requirements given in the EU CHP Directive are preconditions to receiving support
Finland	• Installed CHP capacity: 5.91 GW_{el} • CHP power generation: 28.75 TWh • CHP heat production: 274.5 PJ • CHP-share in power generation: 34.9%	No information	No specific CHP target	• Exemption from renewable energy tax • Tax exemption for biomass CHP • Investment support for biomass CHP
France	• Installed CHP capacity: 5.78 GW_{el} • CHP power generation: 18.42 TWh • CHP heat production: 187.4 PJ • CHP-share in power generation: 3.2%	No information	• **Period till 2015:** Annual decrease in end-use energy intensity (end-use energy consumption divided by GDP) of 2% • **Period 2015 – 2030:** Average annual decrease in end-use energy intensity of 2.5%	• Permanent buy-back obligation for power produced in CHP plants < 12 MW_{el} • Feed-in tariffs for existing non-gas fuelled CHP plants • Exemption from local business tax
Germany	• Installed CHP capacity: 56.33 GW_{el} • CHP power generation: 79.72 TWh • CHP heat production: 646.5 PJ • CHP-share in power generation: 12.5%	National potential study carried out in 2005 by the Bremer Energie Institut identified that the CHP-share in power generation could be increased to maximal 351 TWh_{el}., which represents 57% of Germany's power production	Political target of doubling CHP share in power generation to 25% by 2020	• New CHP-Act in force since January 2009 improves promotion for CHP generation and guarantees degressive feed-in tariffs based on the size of the plant • Investment support for small CHP (< 50 kW_{el}) • Dispatch priority for CHP plants • CHP plants are exempt from the energy tax on fossil fuels if the load factor is above 70% • Additional feed-in tariff for biomass CHP plants

Country	Status (2006)	CHP potential	Political target	CHP promotion policy
Greece	• Installed CHP capacity: 0.25 GW_{el} • CHP power generation: 1.05 TWh • CHP heat production: 8.3 PJ • CHP-share in power generation: 1.7%	Academic study carried out in 2007 by the Hellenic Ministry of Development assumes a CHP potential in 2020 of 2,600 MW_{el}	No specific CHP target	• Fix feed-in tariff for RES and high efficient CHP plants with a capacity < 35 MW_{el} • Purchase obligation and priority dispatch for CHP generation
Hungary	• Installed CHP capacity: 1.98 GW_{el} • CHP power generation: 8.02 TWh • CHP heat production: 46.9 PJ • CHP-share in power generation: 22.4%	No study has been carried out	No specific CHP target	• CHP plants with less than 50 MW_{el} receive obligatory purchase and guaranteed feed-in tariffs • Energy tax reliefs • Investment subsidies
Ireland	• Installed CHP capacity: 0.26 GW_{el} • CHP power generation: 1.54 TWh • CHP heat production: 10.0 PJ • CHP-share in power generation: 5.6%	Potential study carried out in 2006 came to the result that Ireland can “aim to achieve at least” 800 MW_{el} by 2020	Political target of increasing CHP generation by 25 MW_{el} each year	• Capital investment grant and long-term power purchase agreements for CHP generation • Specific promotion schemes for biomass CHP
Italy	• Installed CHP capacity: 6.24 GW_{el} • CHP power generation: 30.89 TWh • CHP heat production: 208.3 PJ • CHP-share in power generation: 9.8%	Study underway	No specific CHP target	• CHP generation benefits from the established certificate scheme and receives energy efficiency certificates (White Certificates) • Exemption from carbon tax and tax break on natural gas consumption
Latvia	• Installed CHP capacity: 0.59 GW_{el} • CHP power generation: 2.08 TWh • CHP heat production: 12.1 PJ • CHP-share in power generation: 42.6%	No specific potential identified	No specific CHP target	• Only CHP for DH is eligible for feed-in tariffs • The promotion depends on fuel type and installed capacity
Lithuania	• Installed CHP capacity: 1.04 GW_{el} • CHP power generation: 1.78 TWh • CHP heat production: 16.9 PJ • CHP-share in power generation: 14.3%	Potential study carried out in 2005 identifies an additional potential between +50% and +100% of the currently installed capacity	No specific CHP target	• Program for implementation of energy saving measures • Only CHP for DH is eligible for feed-in tariffs • Feed-in tariffs for CHP plants fuelled with RES
Luxembourg	• Installed CHP capacity: 0.11 GW_{el} • CHP power generation: 0.47 TWh • CHP heat production: 2.7 PJ • CHP-share in power generation: 10.9%	No information	No specific CHP target	• Government focussed on promotion of renewables • Feed-in tariffs for small CHP plants <1.5MW_{el} • Feed-in tariffs and investment support for biomass CHP
Malta	• Up to now no installed CHP capacity	No information	No specific CHP target	• No policy support

Country	Status (2006)	CHP potential	Political target	CHP promotion policy
Netherlands	• Installed CHP capacity: 7.69 GW_{el} • CHP power generation: 29.42 TWh • CHP heat production: 219.9 PJ • CHP-share in power generation: 29.9%	Inofficial studies identify a potential between 15 – 16 GW_{el}	• Reduction of greenhouse gas emission of 6% by 2012 and 30% by 2020 compared to 1990 • 50 PJ primary energy savings from newly built CHP by 2011	• Feed-in tariffs for CHP applications < 2 MW_{el} based on the CO_2 emissions of the plant • CHP plants with a capacity > 60 kW_{el} receive tax reduction if power efficiency is above 30% • Fiscal investment support for CHP • Investment support for Micro-CHP
Poland	• Installed CHP capacity: 8.47 GW_{el} • CHP power generation: 25.96 TWh • CHP heat production: 264.6 PJ • CHP-share in power generation: 16%	No information	No specific CHP target	• Quota-based system: Energy suppliers are required to purchase cogenerated energy as a proportion of their sales to end consumers • Priority dispatch and purchase obligation for power generated in CHP plants
Portugal	• Installed CHP capacity: 1.1 GW_{el} • CHP power generation: 5.7 TWh • CHP heat production: 63.3 PJ • CHP-share in power generation: 11.6%	Potential Study is in progress	Political target of achieving a total installed CHP capacity of 2,000 MW_{el} by 2010	• Dynamic feed-in tariffs based on avoided costs compared to conventional generation in a centralized gas-fired CCGT plant
Romania	• Installed CHP capacity: 4.12 GWel • CHP power generation: 11.3 TWh • CHP heat production: 99.6 PJ • CHP-share in power generation: 18.0%	No information	No specific CHP target	• No specific support mechanism for CHP generation • Biomass CHP is eligible for green certificates
Slovakia	• Installed CHP capacity: 2.76 GW_{el} • CHP power generation: 8.66 TWh • CHP heat production: 43.6 PJ • CHP-share in power generation: 27.6%	No information	No specific CHP target	• Annually adjusted feed-in tariffs for industrial CHP applications • Purchase obligation for power generated in CHP plants
Slovenia	• Installed CHP capacity: 0.35 GW_{el} • CHP power generation: 1.12 TWh • CHP heat production: 13.5 PJ • CHP-share in power generation: 7.4%	National study identifies a total potential of 0.84 GW_{el}	Political target of increasing CHP power production to 1,600 GWh by 2010	• Feed-in tariff for industrial CHP and DH • Tax exemption for CHP from carbon and fuel tax
Spain	• Installed CHP capacity: 3.87 GW_{el} • CHP power generation: 21.94 TWh • CHP heat production: 188.8 PJ • CHP-share in power generation: 7.2%	National study identifies a potential between 9 and 12 GW_{el}	No specific CHP target	• New legislation in force since 2007 has improved the financial framework for CHP • Feed-in tariff for CHP generation depends on categorization of the CHP installation, power output, and fuel type • Investment support for bio fuel CHP

Country	Status (2006)	CHP potential	Political target	CHP promotion policy
Sweden	• Installed CHP capacity: 3.74 GW_{el} • CHP power generation: 11.43 TWh • CHP heat production: 141.5 PJ • CHP-share in power generation: 8.0%	No information	Government target to phase-out oil-fired CHP plants	• CHP is exempt from energy and carbon tax, and profits indirectly from the high taxation on fossil fuels used for power generation • Electricity certificates for bio fuel CHP
United Kingdom	• Installed CHP capacity: 5.45 GW_{el} • CHP power generation: 25.21 TWh • CHP heat production: 165.5 PJ • CHP-share in power generation: 6.3%	Potential study published in October 2007 identifies an economic CHP potential of up to 17% of total power generation by 2010	Governmental target to attain an installed capacity of "Good-Quality" CHP of at least 10 GW by 2020	• Exemption of good-quality CHP from the Climate Change Levy (CCL) • Good-quality bio fuel CHP receives Renewables Obligation Certificates (ROCs) • Requirement for power station developers to explicitly consider potential for CHP • Good-quality CHP applications commissioned between January 2008 and December 2012 receive free CO_2 allowances within the new entrant reserve allocation • VAT reduction for domestic CHP

Source: own compilation

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